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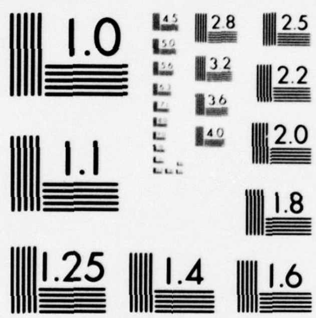

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Appendix to

SEGMAG MACHINES FOR MARINE ELECTRICAL PROPULSION SYSTEMS

Final Technical Report

Contract N00014-76-C-0307

LEVEL III

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SEGMAG MACHINES FOR MARINE ELECTRICAL
PROPULSION SYSTEMS

Final Technical Report

APPENDICES

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APPENDIX NO. 1

VULNERABILITY ANALYSIS FOR VARIOUS MACHINERY ARRANGEMENTS

APPENDIX FOR SECTION 2.1.a

Vulnerability Analysis for Various Machinery Arrangements

This appendix is divided into three sections. The first deals with a further discussion of the material in the main text. The second presents the specific formulas used for the vulnerability analysis, and the third provides background information on general probability with examples related to the analysis.

Comments and Conclusions

The probability that the propulsion system will be inoperative, P_{SYS}, has been computed for five arrangements and a range of values of p, the probability that a zone of length Z will be hit. Generator spaces with or without a motor were always taken to be three zones long. Motor spaces between one to three zones long were investigated.

The text which shows the results plotted in Figures 2.18 and 2.19 discusses the former figure. Figure 2.19 shows the influence of motor room length on the probability of disablement and displays clearly the advantage of restricting the length of the motor rooms.

The baseline arrangement consists of spaces three zones long with one motor and two generators in each of two rooms. In comparison with this arrangement, the following conclusions are reached with regards to placing the motors and generators in separate spaces in order to further improve survivability:

1) The generators should be placed in at least three separate spaces.

2) The motors should be in two separate spaces, each less than three zones long.

Probability Formulas for the Analysis

Assume all machinery spaces are of equal height, and therefore, that the cross sectional (i.e., target) area is proportional to the length of the room. Choose a convenient zone length, Z, such that the shortest room to be considered would be one Z long. Letting Z be 15 ft., motor rooms would be between 1 and 2 Z long and turbine/generator rooms would be 3 Z long. Since a motor may be located beneath a generator, rooms containing a motor and turbine-generator(s) would also be 3 Z long.

For all zones, let the following probabilities hold:

p, probability of hitting a zone

q, probability of not hitting a zone.

It follows that:

$$p + q = 1$$

It is assumed that a hit in any zone within a room is sufficient for that room to be considered disabled.

The probability of hitting one (or more) zones within a room is:

$$P_R = 1 - q^{NZ}$$

whereby NZ is the number of zones in the room.

A set comprises either: 1) all rooms which contain only machines of the same type (i.e., motors only or generators only), or 2) all rooms which contain at least one motor and at least one generator. A set is disabled only when all rooms within the set are inoperative. The probability for this to occur is:

$$P_{set} = P_R^{NR}$$

whereby, NR is the number of rooms in the set.

At this juncture, differentiation is made between machinery arrangements in which all rooms containing at least one motor do or do not also include one or more turbine-generators.

In the first instance, only one set is vital, namely, the one in which all of the rooms of the set contain a minimum of one motor and one generator. The probability that the propulsion system is inoperative is then equal to the probability that the vital set is disabled, or:

$$P_{sys} = P_{set\ M + G}$$

In the second type of arrangement, two vital sets must be considered, i.e., the set which contains motors only and the set which contains generators only. The propulsion system is inoperative whenever either one or both of these sets becomes disabled. The probability of this occurring is:

$$P_{sys} = P_{set\ M}(1 - P_{set\ G}) + P_{set\ G}(1 - P_{set\ M}) + P_{set\ M}P_{set\ G}$$

- Example 1

Take a six compartment arrangement where the motor and generator rooms are 30 ft. and 45 ft. long respectively. If the probability of hitting a zone of 15 ft. length is 0.1, the probability that the system is inoperative may be calculated as follows:

$$p = 0.1$$

$$q = 1 - p = 0.9$$

For the two motor spaces:

$$NR = 2$$

$$NZ = \frac{30\ \text{ft.}}{15\ \text{ft.}} = 2$$

$$P_R = 1 - q^{NZ}$$
$$= 1 - 0.9^2$$
$$= 0.19$$

$$P_{set\ M} = P^{NR}$$
$$= 0.19^2$$
$$= 0.0361$$

And for the four generator spaces:

$$NR = 4$$

$$NZ = \frac{45\ \text{ft.}}{15\ \text{ft.}} = 3$$

$$P_R = 1 - q^{NZ}$$
$$= 1 - 0.9^3$$
$$= 0.271$$

$$P_{set\ G} = P_R^{\ NR}$$
$$= 0.271^4$$
$$= 0.00539$$

The probability that the propulsion system is inoperative is then:

$$P_{sys} = P_{set\ M}(1 - P_{set\ G}) + P_{set\ G}(1 - P_{set\ M}) + P_{set\ M}P_{set\ G}$$

$$= 0.0361(1 - .00539) + 0.00539(1 - 0.0361) + 0.0361 \times 0.00539$$

$$= \underbrace{0.03591}_{\substack{\text{all motors}\\ \text{inoperative}}} + \underbrace{0.00520}_{\substack{\text{all generators}\\ \text{inoperative}}} + \underbrace{0.00019}_{\substack{\text{all motors}\\ \text{and}\\ \text{all generators}\\ \text{inoperative}}}$$

$$= 0.04130$$

<u>Background Information on Probability</u>

In the following discussion of generalized probability theory, the terminology is changed as indicated below:

<u>Vulnerability Analysis</u>		<u>Generalized</u>
Hit, inoperative	⟶	Favorable outcome
No hit, operative	⟶	Unfavorable outcome
A specific time period (i.e., a battle or a mission)	⟶	Trial
Zone, room, set	⟶	Thing

For a single trial and single thing, let p be the probability of a favorable outcome and q be the probability of an unfavorable outcome. If n things have equal probabilities of being favorable (p) and equal probabilities of being unfavorable (q), then the probability of m things being favorable is:

$$P_m = \binom{n}{m} p^m q^{n-m} \qquad (0 \leq m \leq n)$$

whereby the binomial coefficient is:

$$\binom{n}{m} = \binom{n}{n-m} = \frac{n!}{(n-m)!\ m!} = \frac{n(n-1)(n-2)\cdots(n-m+1)}{m(m-1)(m-2)\cdots(3)(2)(1)}$$

and the factorials are:

$$0! = 1$$

$$1! = 1$$

$$2! = (2)(1) = 2$$

$$3! = (3)(2)(1) = 6$$

$$n! = (n)(n-1)\cdots(2)(1)$$

The probability P_m is just one term of the binominal expansion:

$$(p + q)^n = \sum_{m=0}^{n} \binom{n}{m} p^m q^{n-m}$$

Since a single trial for a single thing has only two possible outcomes, the sum of probabilities for the favorable and unfavorable outcomes is unity, or:

$$p + q = 1$$

It is readily seen that the sum of the binominal expansion terms is also 1 since,

$$(p + q)^n = (1)^n = 1$$

This is not only the result one would expect, but this property can also be put to good use in reducing the computation for many probability calculations as shown by the following two examples.

- Example 2

The probability of incurring at least one hit in a room 3 Z long is determined for the case that the probability of hitting a zone is 0.1. One could proceed by calculating the probability that 1, 2, and 3 zones are hit and then taking the sum, or:

$$NZ = 3$$

$$p = 0.1$$

$$q = 0.9$$

One zone hit

$$P_{m=1} = \binom{3}{1}(0.1)^1(0.9)^2$$

$$= 3 \times 0.1 \times 0.81$$

$$= 0.243$$

Two zones hit

$$P_{m=2} = \binom{3}{2}(0.1)^2(0.9)^1$$

$$= 3 \times 0.01 \times 0.9$$

$$= 0.027$$

Three zones hit

$$P_{m=3} = \binom{3}{3}(0.1)^3(0.9)^0$$
$$= 1 \times 0.001 \times 1$$
$$= 0.001$$

At least one zone hit in the room

$$P_r = P_{m=1} + P_{m=2} + P_{m=3}$$
$$= 0.243 + 0.027 + 0.001$$
$$= 0.271$$

- Example 3

Another method for the same case as above is to first calculate the probability that no zones are hit, or:

No zones hit

$$P_{m=0} = \binom{3}{0}(0.1)^0(0.9)^3$$
$$= 1 \times 1 \times 0.729$$
$$= 0.729$$

Since the sum of the probabilities for all possible outcomes (i.e., m = 0, 1, 2, and 3) is unity, the probability of at least one zone being hit is:

At least one zone hit in the room

$$P = 1 - P_{m=0}$$
$$= 1 - 0.729$$
$$= 0.271$$

As can be seen from the two examples above, the second calculation method is shorter than the first for the case considered. Using this second method, the probability of at least one zone being hit for a room with NZ zones leads to the formula given in the previous part of this appendix, i.e., $P_r = 1 - q^{NZ}$.

- Example 4

Returning to the case given in example 1, the probability of all four generators being inoperative was 0.00539. If it were of interest to know the probability that m generators were disabled, the following calculations would be made:

$$P_R = 0.271$$

$$Q_R = 1 - P_R = 0.729$$

$$NR = 4$$

No generators inoperative

$$P_{m=0} = \binom{4}{0}(0.271)^0(0.729)^4 = 0.28243$$

1 generator inoperative

$$P_{m=1} = \binom{4}{1}(0.271)^1(0.729)^3 = 0.41996$$

2 generators inoperative

$$P_{m=2} = \binom{4}{2}(0.271)^2(0.729)^2 = 0.23418$$

3 generators inoperative

$$P_{m=3} = \binom{4}{3}(0.271)^3(0.729)^1 = 0.05804$$

4 generators inoperative

$$P_{m\,=\,4} = \binom{4}{4}(0.271)^4(0.729)^0 = 0.00539$$

- Example 5

Likewise, the probability that m motors are disabled can be determined as follows:

$$P_R = 0.19$$
$$Q_R = 0.81$$
$$N_R = 2$$

No motors inoperative

$$P_{m\,=\,0} = \binom{2}{0}(0.19)^0(0.81)^2 = 0.65610$$

1 motor inoperative

$$P_{m\,=\,1} = \binom{2}{1}(0.19)^1(0.81)^1 = 0.30780$$

2 motors inoperative

$$P_{m\,=\,2} = \binom{2}{2}(0.19)^2(0.81)^0 = 0.03610$$

The discussion now turns attention to cases where the probabilities of favorable outcomes for n things are not all equal. Table 1 shows the probability of m of n things being favorable for n equal to 1, 2, and 3.

TABLE 1. PROBABILITY OF m THINGS BEING FAVORABLE

n	Unequal Probabilities	Equal Probabilities
1	$P_{m=0} = q$	q
	$P_{m=1} = p$	p
2	$P_{m=0} = q_1 q_2$	q^2
	$P_{m=1} = p_1 q_2 + p_2 q_1$	$2pq$
	$P_{m=2} = p_1 p_2$	p^2
3	$P_{m=0} = q_1 q_2 q_3$	q^3
	$P_{m=1} = p_1 q_2 q_3 + p_2 q_1 q_3 + p_3 q_1 q_2$	$3pq^2$
	$P_{m=2} = p_1 p_2 q_3 + p_1 p_3 q_2 + p_2 p_3 q_1$	$3p^2 q$
	$P_{m=3} = p_1 p_2 p_3$	p^3

Referring to example 1, the probability that the propulsion system will be inoperative could be determined by first calculating the probability that the sets are operative, or:

$$Q_{set\ M} = 1 - P_{set\ M} = 1 - 0.03610 = 0.96390$$

$$Q_{set\ G} = 1 - P_{set\ G} = 1 - 0.00539 = 0.99461$$

Since at least one motor and one generator must be operative for the propulsion system to drive the ship, the probability that the system will be operative is given by the product of the Q's:

$$Q_{sys} = Q_{set\ M}\, Q_{set\ G} = 0.96390 \times 0.99461 = 0.95870$$

The probability that the propulsion system will be inoperative is then:

$$P_{sys} = 1 - Q_{sys} = 1 - 0.95870 = 0.04130$$

As the final part of this appendix, an examination will be made of the various combinations of disabled motors and generators. For the six space arrangement of example 1, there are three possible conditions for the motors, i.e., 0, 1, or 2 motors inoperative. For the generators, there are five possible states which gives a total of 15 possible combinations for the system. The probability of occurrence for each combination is shown in Table 2.

TABLE 2. PROBABILITY OF COMBINATIONS OF MOTORS AND GENERATORS BEING INOPERATIVE

Probability		Number of Generators Inoperative				
		0	1	2	3	4
Number of	0	0.18530	0.27554	0.15365	0.03808	0.00354
Motors	1	0.08693	0.12926	0.07208	0.01786	0.00166
Inoperative	2	0.01020	0.01516	0.00845	0.00210	0.00019

NOTES: 1) $p = 0.1$

2) 2 motor rooms - 2 Z long

3) 4 generator rooms - 3 Z long

The values for Table 2 were calculated using the results of examples 4 and 5. For instance, the probability that one motor and two generators will be inoperative is calculated as follows:

1 motor inoperative

$$P_{m = 1\ M} = 0.30780$$

2 generators inoperative

$$P_{m = 2\ G} = 0.23418$$

1 motor and 2 generators inoperative

$$P = (P_{m = 1\ M})(P_{m = 2\ G}) = 0.30780 \times 0.23418 = 0.07208$$

The values listed in Table 2 may be used to determine the probability of occurrence of various propulsion system states, some of which are discussed in the following paragraphs.

The system is *disabled* whenever two motors, four generators, or all six machines are inoperative. Summing the probabilities for all possible combinations gives the probability that the propulsion system will be inoperative, or:

$$\begin{array}{r} 0.00354 \\ 0.00166 \\ 0.01020 \\ 0.01516 \\ 0.00845 \\ 0.00210 \\ 0.00019 \\ \hline P_{sys} = 0.04130 \end{array}$$

Likewise, the probability that the system will be operative is found by summing the probabilities for all combinations where at least one motor and one generator are operative, or:

$$
\begin{array}{r}
0.18530 \\
0.27554 \\
0.15365 \\
0.03808 \\
0.08693 \\
0.12926 \\
0.07208 \\
0.01786 \\
\hline
Q_{sys} = 0.95870
\end{array}
$$

The sum of P_{sys} and Q_{sys} is one since these are the only two possible outcomes, i.e., the system either is or is no operative.

Suppose the probability were to be determined that at least one shaft could be driven at full power. This requirement would be met as long as only 0 or 1 motors and 0, 1, or 2 generators were disabled. Summing the probabilities for the six possible combinations gives:

$$
\begin{array}{r}
0.18530 \\
0.27554 \\
0.15365 \\
0.08693 \\
0.12926 \\
0.07208 \\
\hline
= 0.90276
\end{array}
$$

Probability that at least one shaft can be driven at full power = 0.90276

The probability that the propulsion system will be totally undamaged is 0.18530, i.e., zero motors and zero generators *inoperative*. This result could also be obtained by recognizing that all zones must be unhit in order for the system to be totally undamaged. The number of motor and generator zones is: 2 x 2 = 4 and 4 x 3 = 12 respectively which results in a total of 16 zones for the propulsion system. The probability that none of the zones will be hit is then:

$$Q_{\text{all zones}} = q^{(\text{total number of zones})}$$

$$= 0.9^{16}$$

$$= 0.18530$$

As a final note, the relative merit of various machinery arrangements is clearly established for p less than 0.1. Although the relative vulnerability may change for p greater than 0.25, this range (i.e., $0.25 \leq p \leq 1.0$) is of little interest since with a high hit probability it is questionable whether the ship would even survive let alone the propulsion system.

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APPENDIX NO. 2

GAS TURBINE PERFORMANCE

APPENDIX

GAS TURBINE PERFORMANCE

The steady state gas turbine characteristics are taken from General Electric report MID-TD-2500-8, April 1977, "7LM2500 Marine Gas Turbine Performance Data". The report presents average engine performance over a range of temperatures with correction factor curves for such effects as duct losses, humidity, etc.

For the purposes of determining the propulsion system operating characteristics, the tabulated data on pages 145 through 154 of the GE report was used. Based upon the tabulated values, the gas turbine SFC (specific fuel consumption) is shown in Figure 1 plotted against engine power and power turbine speed. The following assumptions and conditions apply to this data:

- o An average engine in the new and clean condition.
- o An ambient temperature of 59°F, pressure of 14.696 psia, and zero humidity.
- o No duct losses.
- o A fuel lower heating value of 18,400 BTU/lb.
- o Zero engine bleed and zero accessory drive takeoff.

For other conditions, correction factors may be applied or, in the case of a different inlet temperature, other sets of tabulated data may be used. As an example, the SFC as a function of ambient temperature is shown in Figure 2 for two constant power operating points. The first plot, Figure 2a, corresponds to the power turbine load and speed at rated conditions for the 40 khp/shaft

propulsion system. The second plot corresponds to cruise conditions.

For these examples, duct losses of 4 and 6 inches of water have been assigned for the inlet and exhaust, respectively, at rated power and an ambient temperature of 59°F. The correction factors are 1.0030 (inlet) and 1.0075 (exit) which gives a correction factor of 1.0105 for the total duct losses (i.e., 1.0030 x 1.0075 = 1.0105). The duct losses at other conditions are estimated to vary as the square of the inlet corrected air flow.

The SFC two sigma variation to the tabulated data is reported to be 1.7 percent on a constant power basis. Assuming a normal distribution, the performance of 95.5 percent of all new engines would fall within the ± two sigma band shown on the plots.

Also shown in Figure 2 are the two points which correspond to the rated and cruise power conditions given in Section A2.3.1. That is, average performance at an ambient temperature of 59°F with zero duct losses.

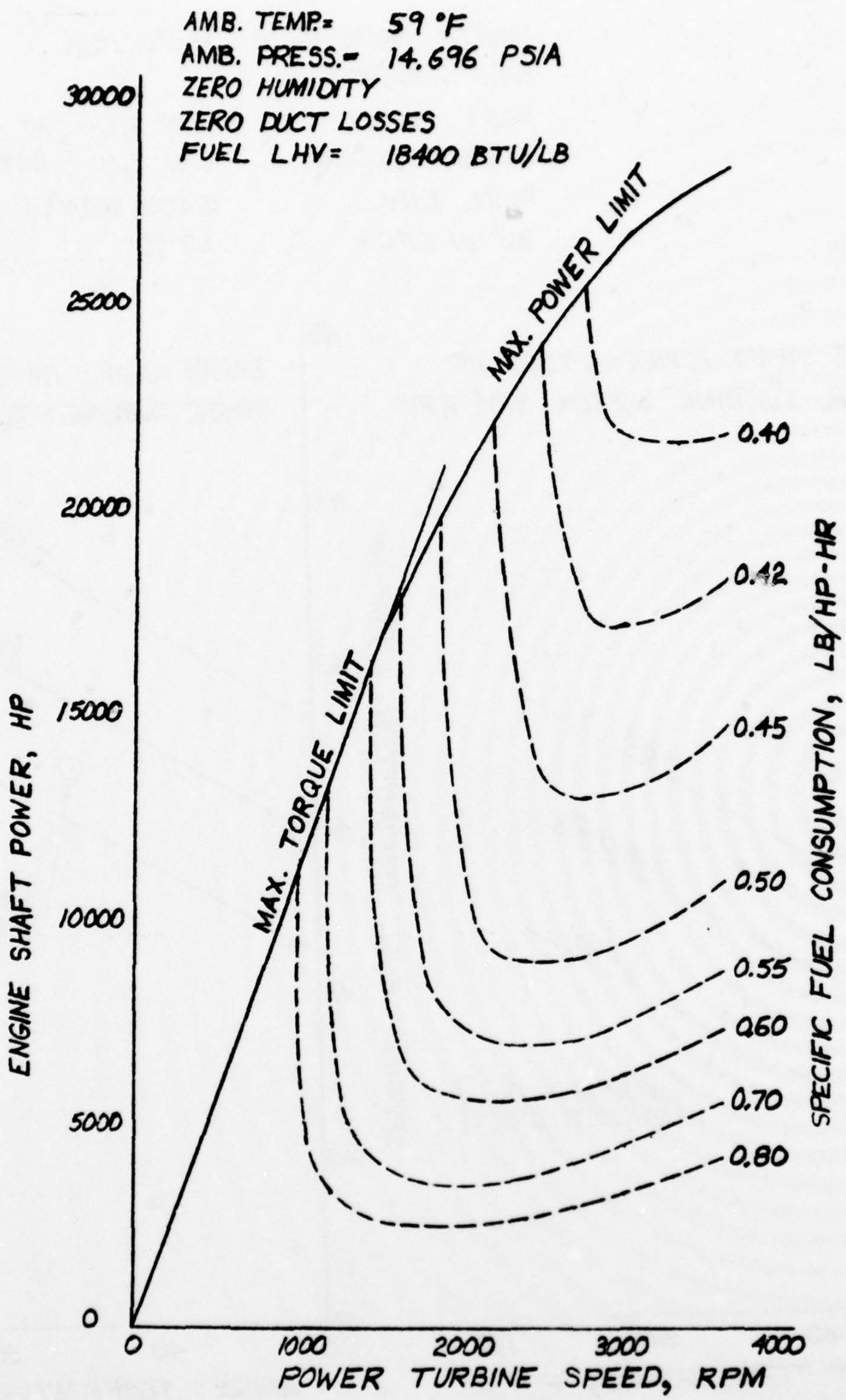

Figure 1 LM2500 Marine Gas Turbine
Estimated Average Performance

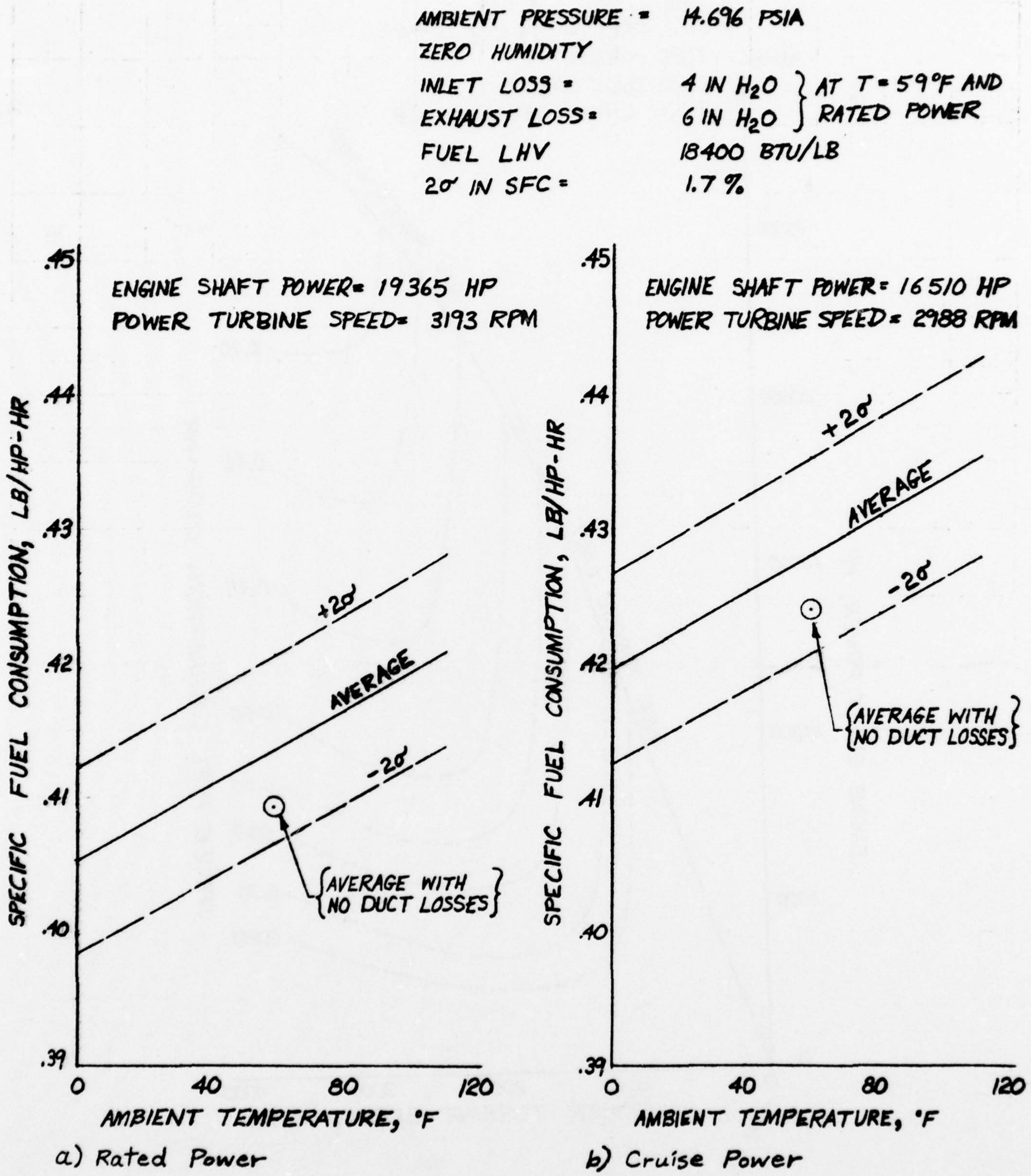

Figure 2 LM2500 Marine Gas Turbine Estimated Performance

APPENDIX NO. 3

BRAKE DESIGN REVIEW FOR A SHIP
ELECTRICAL PROPULSION SYSTEM

REPORT F - A7707

January 11, 1978

BRAKE DESIGN REVIEW

for an

ELECTRIC SHIP PROPULSION DEVELOPMENT

by

R. Clyde Herrick

under

WEC Purchase Order 7S1-77831-1A610

for

WESTINGHOUSE ELECTRIC COMPANY
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POWER SYSTEM DYNAMICS, INC.

CONTENTS

POWER SYSTEM DYNAMICS, INC.

INTRODUCTION

On November 30, 1977, the author met at the WEC Pittsburgh R&D Center with William P. Welch and Raymon A. Feranchak to review a brake design for the electric ship propulsion system now under development. A proposed brake had already been recommended by others, consisting of 29 disks employing 28 active friction surfaces of the same size used in the DD-963 Destroyer Program. The purpose of this report is to convey the results of a brief review of this brake and its application to the electric propulsion requirements.

SUMMARY

As expanded in the following technical discussion the previously recommended oil coolant flow of 320 GPM was confirmed by showing that a minimum of 292 GPM is necessary to limit the maximum oil temperature rise to 125°F. For added conservatism, 320 GPM may be used to limit the exit oil to a 100°F rise.

The proposed design is sized well with respect to torque at high slip speed (14,000 FPM approx.), but spline friction on the 29 disks may reduce the disk pack effeciency to 0.72 and thereby cause the first friction surface to be subjected to a heat generation rate 39 percent higher than the pack average. The average heat generation rate (throughout the disk pack) per unit area is 0.944 HP/ sq. in. With a disk pack effeciency of 0.72 the first active surface may be subjected to a heat rate of 1.31 HP/ sq. in. This is on the high side for both graphitic and paper friction materials at a sliding velocity of 14,000 FPM. Tests should be conducted to assure that adequate life is achieved.

Additional study is required for the selection of a friction material. Paper has performed with limited life in this range of loading for one clutch/ brake manufacturer but experience is limited. A more recent graphitic material has been reported to be capable of these energy rates but supporting test data has not been received to date. A very recent phone call has now assured that the data will be forthcoming very soon.

Additional heat capacity of the brake to reduce the temperature at the

friction interface appears to be possible. As a minimum, the thickness of the steel disks and possibly the friction disk cores can be at least doubled. Additional study is required.

The oil distribution shown is satisfactory and need not be distributed to more than 4 points around the circumference--- the high rotational speed will distribute the oil. Oil should be directed onto a cylindrical hub through which holes are drilled in a precise pattern to distribute oil to the friction disks. Hole sizing and spacing controls the axial distribution. Centrifugal force supplies the pressure.

RECOMMENDATIONS

A. With respect to the choice of the friction material a further study is warranted to determine that available friction materials can produce the required life. This should include tests of a disk to simulate the heat generation and heat capacity of the disks.

B. Design studies can show alternate designs including somewhat larger diameter and actuation from each end to (1) increase the disk pack effeciency (2) reduce the unit heat generation rate, and (3) possibly reduce the friction interface maximum temperature by increasing heat absorption by the disks.

TECHNICAL DISCUSSION

Heat Capacity and Dissipation

Adequate cooling is imperative. The design enclosed with WEC memo dated Nov. 22, 1977 has a small heat absorption capacity as compared to the total heat generated. The 15 steel drive plates at a temperature rise of 150 F and 14 friction disk cores (steel) at a temperature rise of 100 F only account for 1707 BTU and 1062 BTU, respectively, or 2769 BTU total. This is only about 21% of the 12,988 BTU (13.7×10^6 joules) dissipated in the brakes. Therefore, the major portion of the heat must be dissipated by the cooling oil circulated through the brake.

Since the steel heats quickly (see later discussion), and since the brake is applied twice in quick succession, it is appropriate and only somewhat conservative to base the cooling rate on the higher heat generation rate of the second application. This second application is seen to peak at 2.4 MW-(3217 HP or 2274 BTU/sec.) above an average rate of 2.29 MW (3064 HP or 2165 BTU sec.) for the 4.0 second breaking period. Coolant oil (specifications to be discussed later) has a heat removal capacity of 0.0592 BTU/sec-°F for each GPM passing through the brake. For the average heat rate of 2165 BTU/sec., the trade-off between the temperature rise and coolant flow rate is:

$$\frac{2165 \text{ BTU/sec}}{0.0592 \text{ BTU/sec-}^\circ\text{F-GPM}} = 36{,}570^\circ\text{F-GPM}$$

Temp Rise	Flow Rate
100°F	365.7 GPM
125°F	292.6 GPM

The above is based upon a mean specific heat for the oil of 0.48 BTU/lb-°F and oil of Specific Gravity 0.887 or 7.4 lb/ Gal.

Since the DD-963 shaft brake gives evidence of satisfactory performance at a measured (and calculated) temperature rise of 170°F to 200°F, the choice of 125°F for the limiting design temperature rise appears in this respect, conservative. Actually, it is not. This brake has a much greater speed of 3600 rpm, mean, as compared to the DD-963 turbine shaft brake that stops the turbine shaft from a maximum speed of 2300 rpm. In addition, this propulsion brake acts only 4.0 seconds in this application so that variations that may occur due to system

conditions or to control actuation time may become significant as compared to the application time. Therefore, the minimum theoretical coolant flow rate is 293 GPM. Basically, this is needed only during active breaking, but actually, it needs to be started sufficiently in advance so that its flow rate can be sensed as a permissive for brake application. It should be continued for a brief period, 2 to 3 seconds minimum, after the brake is released to (1) aid in spreading the plates for minimum drag, and (2) to remove some residual heat. The coolant flow may then be reduced to a continuous supply of approximately 40 GPM. This is required to cool the brake and provide adequate lubrication of the plates when running disengaged.

Type of Coolant and Lubricant

For best results, lubrication and cooling should be provided by the use of General Motors Specification C-2 Fluid or Dexron Automatic Transmission Fluid. These are especially formulated and compounded to provide adequate lubrication and to remain stable under the high temperatures encountered. These fluids are formulated by all oil companies and are available worldwide, economically. The added friction modifiers produce a more uniform coefficient of friction and reduce wear as compared to untreated mineral oils.

Brake Design Parameters

A highly recommended aid for the design of brakes is Section 28, Friction Clutches and Brakes, Mechanical Design and Systems Handbook by Rothbart, published by McGraw-Hill Book Company, 1964. Analytical relationships are given there for determining the braking torques available from various sizes and pressures available. A more simplified restatement of the relationship for torque is:

$$T = \alpha \mu A P N \bar{R}$$

where α = Pack Efficiency
μ = Coefficient of Friction
A = Piston Area
P = Piston Pressure
N = No. of Active Surfaces
$\bar{R}$ = Mean Radius of Friction Surface

This follows the uniform wear theory of friction brakes.

Torque is basically the product of the applied axial clamping force (AP), the moment arm ($\bar{R}$), the number of active surfaces (N) and the coefficient of friction (μ). This is modified by the disk pack efficiency (α) which arises from the friction on the splines which reduces the effective axial force transmitted from plate to plate throughout the active disk pack. It becomes particularly limiting when the number of disks becomes large. An attached calculation of the mean effective pressure throughout the brake shows that the proposed brake has a disk pack efficiency, α, of 0.72. This means that the brake supplies only 72 percent of the torque that could be developed if no spline friction were present or if the brake contained only one active surface. More importantly, it states that the applied pressure must be 39 percent greater than the mean effective pressure. It means that the first active surface must be capable of assuming a 39 percent greater heat load than the brake as a whole, and that 39 percent greater oil flow must be supplied to the first active surface. The total oil flow need not be increased, just the distribution to the active friction surfaces. This is accomplished by proportioning the holes in the hub admitting oil to the active surfaces.

An alternative would be to actuate the brake at each end with a common reaction point in the center. Reducing the number of disks to 15 or one-half the active surfaces increases the disk pack efficiency to 0.844 so that the first active surface recieves only 1.185 times that of the average.

On a per unit basis, the heat rate and coolant flow rate are compared to that for the DD-963 turbine brake in Table 1. Note that in the average, the maximum heat rate per square inch is 1.64 times that of the DD-963, while the oil flow rate is 3.2 times, to give a net lower temperature. Thus, the thermal balance of the brake appears to be in good order provided a material is used which can withstand the local temperature at the friction surface; that is, that the material can perform at the indicated heat generation rates and the stated slip speeds.

Review of Applicable Friction Materials

Generally, most high energy friction materials are used in automotive or off-highway equipment where the braking time or shifting time is on the order pf 0.4 to 0.7 sec. Under these circumstances, designs allow heat rates in excess of 3 HP/ in^2. However, as both the surface speed and the engagement time increases, either together or separately, the allowable energy rate per unit friction area

decreased. Only a few friction materials are known to have given satisfactory service at the speeds and energy densities shown in Table 1 to be required for the proposed electric propulsion brake. Materials that have been successful have included certain of the "paper"friction materials, recent graphitic materials and the teflon materials.

Paper materials hold up surprisingly well in higher energy level clutches and brakes the high porosity of the material holds an initial quantity of oil and permits a fair amount of oil to flow through the paper material to remove the heat generated. However, little data is available to document applications in this region. Philadelphia Gear Corporation has used paper materials successfully to and beyond 1.0 HP/inch^2. However, the allowable number of engagements falls rapidly upon passing 1.0 HP/in^2; that is, wear per engagement becomes quite significant. Since this is the region of operation of the proposed brake, tests should be conducted to verify that the life of paper material would be satisfactory.

The next class of materials for consideration is that of the graphitics. Generally graphitic friction material is used for high energy density (high heat rate) applications where constant coefficient of friction is not so important. The material will produce a "rooster-tail," or higher torque, as the sliding velocity becomes very low. It was anticipated that a more recent graphitic material could be compared to the requirements here to assess its applicability. However, the promised test data from the manufacturer has not been received. Two critical users have been contacted who verify satisfactory hagh energy application in their products. Unfortunately, their application in heavy off-highway equipment utilizes much shorter engagement times. Although the sliding velocity and heat rate may be comparable, the data does not necessarily validate performance at longer engagement times. The newer material is Rayflex C-6475-4 manufactured by RM Friction Materials Company. The data will be forwarded when received.

In place of the newer material, the applicability of an older widely used graphitic material will be discussed here. This is material HDT-303 manufactured by the SK Wellman Co. and used for both the propulsion clutches and turbine brakes of the DD-963 Destroyer program. Figure 1, 2 and 3 plus Table 2 show the published limitations of this graphitic material. Figure 1 indicates that, at 6000 FPM, the material showed wear of only 3.5 mils after 2000 engagements at

an energy rate of 1.5 HP/ in^2 with an oil flow of 0.048 GPM/ in^2 or approximately half the minimum rate stated for the proposed propulsion brake. Table 2 also indicates successful results at both 1.0 and 1.5 HP/ sq. in. for long term drag up to 12 seconds duration. Unfortunately, this latter test data was obtained at a sliding velocity of 3200 FPM. Figure 2 is primarily a graphic presentation of the Table 2 data. The sliding velocity is too low for direct applicability to the electric propulsion brake. Figure 3 is a graphic summary that does include the results of tests at 12,000 FPM which is sufficiently close to the mean speed of14,000 FPM to be directly applicable. Note the significant drop in allowable total energy per engagement. Note also that the proposed brake would have a HP/GPM ratio equal to 10.9. The test data lacks specific tests at this higher oil flow to determine what happens at 10.9 HP/ GPM. Extrapulation of the 1.0 and 1.5 HP/ sq. in. data lines to test value project limits of 1000 and 800 FT-LB, respectively, for the total energy dissipated each engagement. These energies are both well below the required energies per 4.0 second engagement of the proposed brake which requires 1397 FT-LBS without considering the disk pack efficiency, or a maximum of 1942 FT-LBS for the first active friction surface with a disk pack efficiency of 0.72. Thus, tests would also be required to verify the applicability of this material as well.

The highest energy friction lining available at this time is a class of modified Teflon materials, a trade name of which is Gylon, by Garlock, Inc. Data for the required speeds and heat rates on this material has also not been received as yet. While the material is said to be expensive, there seems to be general agreement that the material holds the best promise for higher, longer term heat rates.

Required Actuation Pressure

Actuation pressure depends, to a certain degree, upon the choice of material, lubricant and the disk pack efficiency. Generally, the actual coefficients of friction run between 0.06 for very high speed, high pressure, engagements to 0.13 for the moderate speed, lower pressure engagements. These values apply to both paper and graphitic materials. Past experience indicates that, for the electric propulsion brake, the product of pack efficiency and coefficient of friction may be estimated at a value of $\alpha\mu = 0.075$.

The attached calculation for actuation pressure shows that a relatively low net pressure of 29 psi on the gross friction surface is required to produce 4500 FT-LB. torque. Please note that this is the pressure on the 121.6 sq. inch friction surface. Actuation pressure in an actuating piston and cylinder is arbitrary so long as the axial clamping force is equal to 3526 pounds (121.6 sq. in. x 29 psi) plus additional pressure to depress the piston return springs and overcome seal friction. If hydraulic pressure is used the pressure must be high enough to use good quality regulation components. Pressure between 300 and 1000 psi are recommended for prompt hydraulic actuation and yet provide excellent seal life.

Increasing Brake Heat Capacity

Investigations have been made toward increasing the heat storage capacity of the brake in an effort to reduce the required oil flow rate. As previously stated, assuming a 150 F temperature rise of the steel disks and 100 F temperature rise of the friction disk cores (steel) yields a heat storage capacity of 2970 BTU. While this is only about 23 percent of the total heat generated, 12988 BTU, the steel disks heat so quickly that even this small amount of heat storage can not be used effectively to reduce the maximum temperature rise. Investigations made using a linearly decreasing heat generation ramp function show that the steel drive disks are essentially up to temperature in approximately one second under the heat rate and oil flow required for the brake.

The high response rate of the steel disks offers the possibility of increasing the steel thickness to a point short of the temperature difference between disk surface and disk center that could produce cracks. It appears that the thickness of the steel could be at least doubled, if not made even greater. However, not much is gained unless the time to heat the steel is increased to a point that it reduces the maximum temperatures in the friction material. This is the secret of the high allowable heat rates for the short duration braking times. Rather than just lengthening the disk pack it may be more advantageous to choose a slightly larger diameter so as to increase the disk pack efficiency and reduce the peak heat load on the first active surface two ways. Just how far this can be carried must be reserved for a later study.

More way-out solutions such as the use of beryllium are interesting but limited in potential. In spite of the fact that beryllium has a specific heat 4.7 times that of steel, and a thermal conductivity twice that of steel, the density is only about 23 percent that of steel to make the heat capacity on a volume to volume basis about the same as steel, but much more expensive. If we were designing airplanes or space crafts, it would be great.

Actually, instead of considering more exotic metals, project funds could be much better spent in adapting and testing the available teflon based friction materials.

TABLES and FIGURES

Table 1

Parameter	Electric Propulsion	DD-963
Friction Surface OD	17.37 inches	17.37 inches
Friction surface ID	12.12 inches	12.12 inches
Friction Area per disk	121.6 in^2	121.6 in^2
No. Active Surfaces	28	12
Disk Pack efficiency	72%	86%
Total Gross Area	3408 in^2	1459 in^2
Max. Heat Rate	3217 HP 2274 BTU/sec	837 HP 591 BTU/ sec
Heat rate per sq. inch	0.944 HP/in^2 0.667 BTU/ sec-in^2	0.574 HP/ in^2 0.406 BTU/ sec-in^2
Heat rate per sq. inch with pack eff.	1.31 HP/in^2 0.926 BTU/ sec-in^2	0.667 HP/ in^2 0.472 BTU/ sec-in^2
Oil Flow Rate	292 GPM, min. 0.086 GPM/ in^2	40 GPM 0.027 GPM/ in^2
Max. Oil Temp. Rise	125 F	187 F

TABLE 2

HP/in²	GPM/in²	RATIO H.P./GPM	DRAG/IDLE sec/cy	KINETIC ENERGY, Ft-lb/in²/cy	OIL OUTLET °F(end eng)	NO.ENG.	FRICTION WEAR, mils	WEAR PER 100 Engs	COEFF. OF FRIC.
0.5	.01	50	10/20	2750	245	120	1.1	0.9	.097
0.5	.02	25	12/48	3280	325	300	2.6	0.9	.082*
1.0	.02	50	10/20	5500	262	120	4.3	3.6	.111
1.0	.02	50	12/48	6560	360	90	25.1	28.0	.113*
1.0	.04	25	12/48	6560	325	120	24.7	20.6	.108*
1.0	.06	16	12/48	6560	295	380	12.9	3.4	.097*
1.25	.02	62	10/20	6875	309	60	F		.109
1.25	.03	42	10/20	6875	382	72	F		.103
1.25	.03	42	10/20	6875	382	90	F		.103
1.25	.04	31	10/20	6875	288	120	11.5	9.6	.106
1.50	.02	75	10/20	8250	362	20	F		.104
1.50	.04	37	5/25	4120		350	7.5	2.1	.098
1.50	.04	37	6/24	4950	296	55	23.2	42.0	.112
1.50	.04	37	7/23	5770	318	15	10.2	68.0	.104
1.50	.04	37	10/20	8250	287	40	F		.105
1.50	.08	19	12/48	9930	340	25	9.0	36.0	.110
2.00	.04	50	3/27	3320	260	100	8.5	8.5	.108
2.00	.04	50	4/26	4400	289	20	19.2	96.0	.103

* Pack insulated from fixture.

F = failure

REPORT R-79-86

FIG. 1

EFFECTS OF ENERGY, OIL FLOW, AND HORSEPOWER
ON HDT-303

CLUTCH UNIT - CRT
NO. DISCS - 1 (14.6 x 12.7)
NO. ENGAGEMENTS - 2000
GROOVING - 63/44 diamond

SPEED - 1675 RPM (6000 FPM)
OIL TYPE - D-A Torque Fluid
O.P. - SAE 1070 Steel

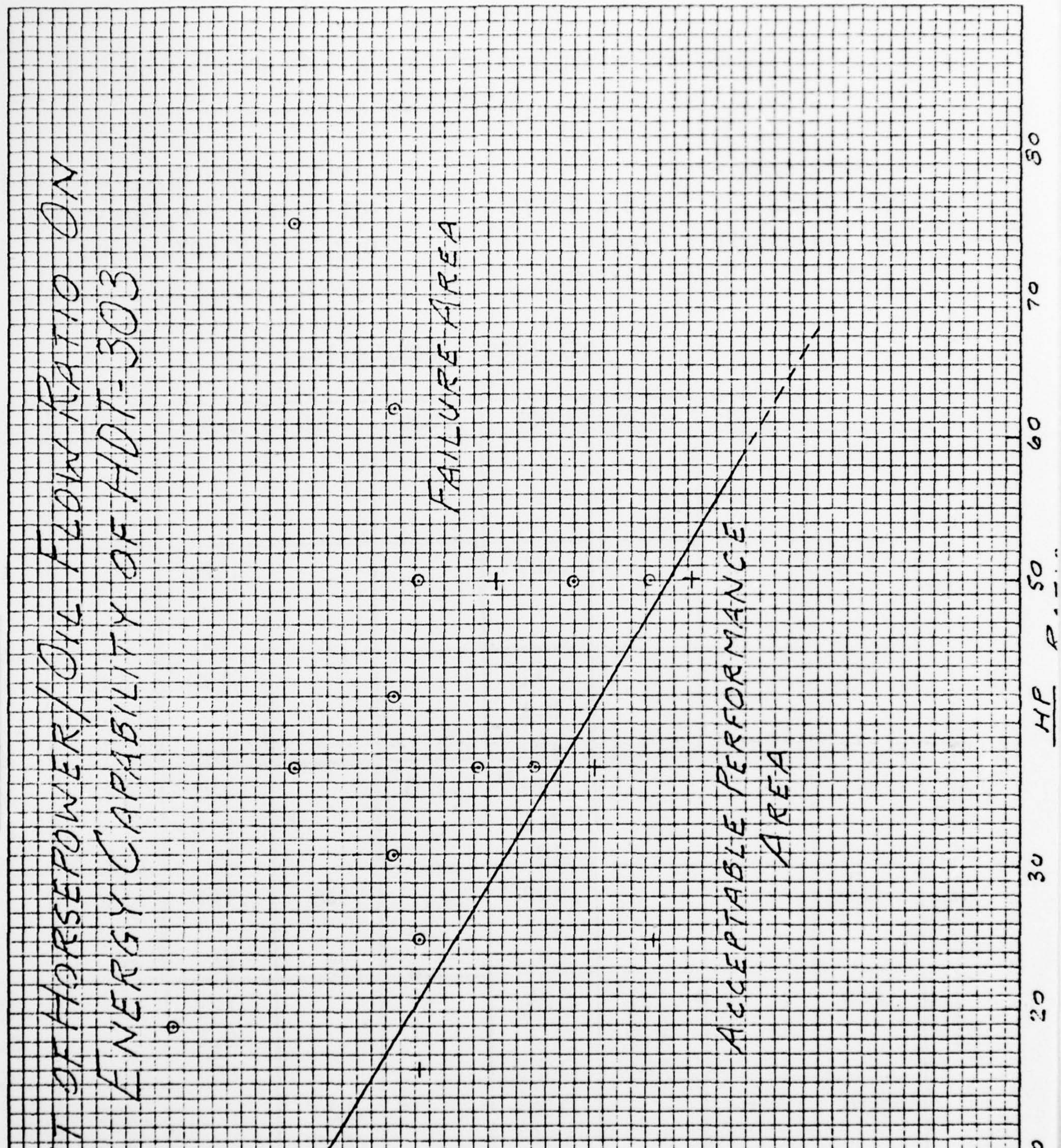
OIL FLOW - GPM/Sq.In.

	.048	.036	.024	.020	.016	.012	.008	.004
347								.122
535			.127 [2]			.121 [2] 19		.136 10
724			.117 [2] 2.1 18			.130 [1½] 12	.123	.131 20
910			.129 [1½] 2.1 10	.128 [1½]		.127 [1½] 2.6 19	.121 14	.127 2.4 26
1100			.122 [1½] 2.1 17		.125 15	.128 16	.130 2.3 21	
1280		.121 [1½] 2.8 20	.124 17			.123 2.4 25		.133 2.4 40
1510	.126 14		.122 2.4 24		.124 2.5 29		.130 2.5 36	
1660	.120 [1½] 3.5 29		.118 [1½] 3.1 26					

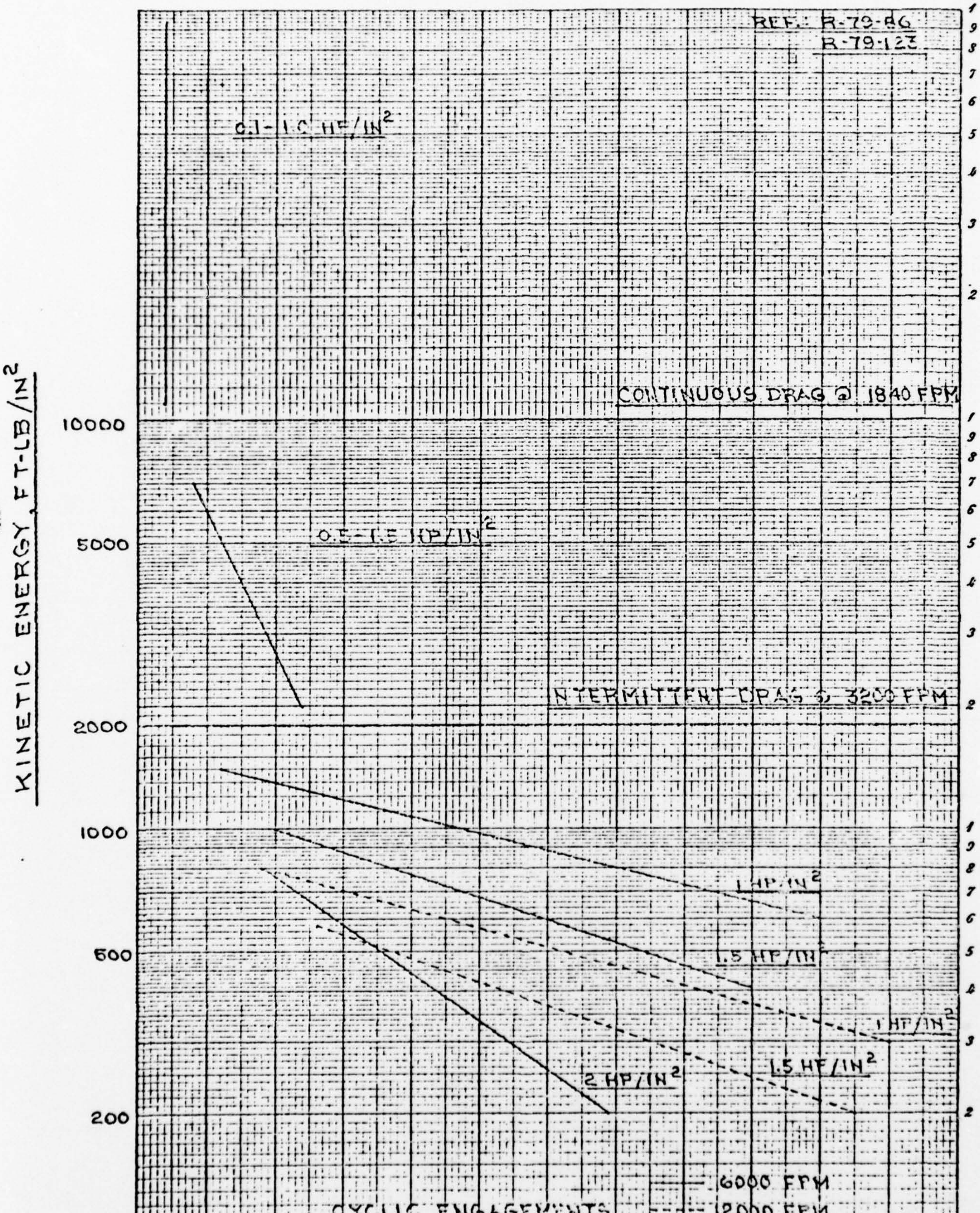
Values represent dynamic μ, wear in mils, and opposing plate distortion in mils.

Upper right corner - unit horsepower (1 hp/in^2 where not indicated)

Figure 2


EFFECT OF HORSEPOWER/OIL FLOW RATIO ON
ENERGY CAPABILITY OF HDT-303
FAILURE AREA
ACCEPTABLE PERFORMANCE
AREA
0
10
20
30
50
60
70
80
HP
x1000

ENERGY, HORSEPOWER, OIL FLOW ON HDT-303



POWER SYSTEM DYNAMICS, INC.

CALCULATIONS

REQUIRED NET ACTUATION PRESSURE

Torque Formula

$$T = \alpha\mu P A N \bar{R}$$

N = 28 Active Surfaces
$\bar{R}$ = 7.333 inch mean Radius
A = 121.6 in^2 friction Area
T = 4500 FT-LB, Torque
$\alpha\mu$ = 0.075

Required Pressure

$$P = \frac{T}{\alpha\mu A N \bar{R}}$$

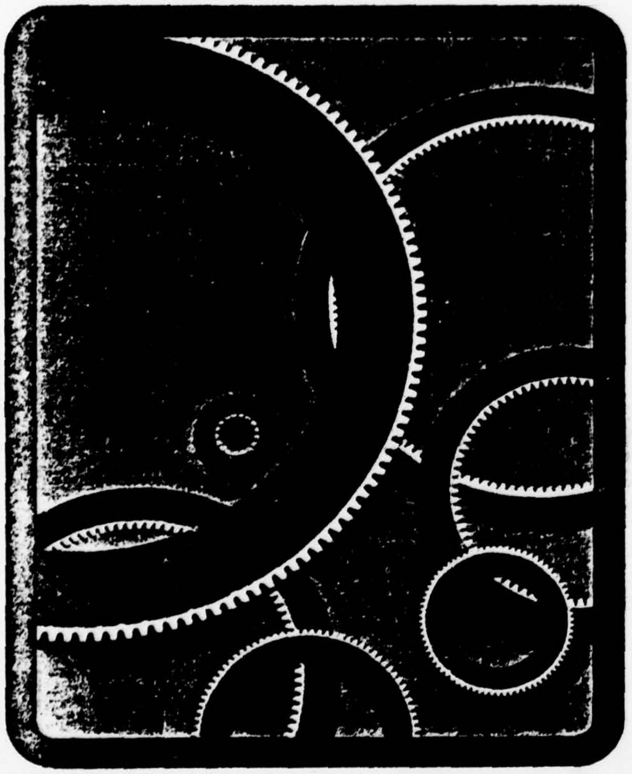
$$P = \frac{4500 \times (12 \text{ IN/FT.})}{(0.075)(121.6)(7.333)(28)}$$

P = 29 psi, net pressure on Gross Friction Area

HIGH PERFORMANCE

Rayflex™

PATENT PENDING



Although C-6475-4 is considered a member of the graphite family, it is a uniquely different friction material. The material provides a high performance friction product for wet brakes and clutches and is characterized by the following advantages:

HIGH FRICTION WITH ENERGY CAPACITY

With an energy capacity nearly double that of bronze and a typical dynamic coefficient of friction of .12, the designer has the option to, 1) Use fewer plates, 2) Use lower apply pressure, 3) Increase the torque capacity, 4) Reduce the transmission size and weight.

EXCELLENT DURABILITY AND COMPATABILITY

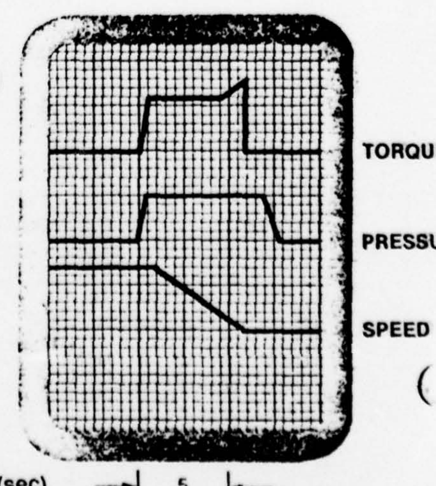
C-6475-4 exhibits minimal sensitivity to oil grade and additive packages. The material has excellent durability and minimum friction decay with extended use. Due to greater structural integrity, break-in contamination of the oil has been virtually eliminated. Its resilience and flexibility reduces erosion due to mechanical and thermal fatigue and is compatible with surfaces from 5 to 80 micro-inch finish.

TRANSMISSION TEST

Speed
7000 ft/min

Pressure
250 PSI

Energy
867 ft/lbs/in²
(1.11 BTU/in²)



A NEW AND DIFFERENT MATERIAL FOR WET FRICTION APPLICATIONS

VERSATILITY

C-6475-4 will provide long life in nearly all applications from light duty to severe high temperature use. By varying groove pattern, the friction level and performance characteristics can be tailored to meet specific application requirements.

IMPROVED PERFORMANCE IN WET FRICTION APPLICATIONS

Typical applications for C-6475-4 are:

- On and Off-highway powershift transmission clutches
- Crawler steer clutches and brakes
- Farm and construction equipment wheel brakes
- Farm and construction equipment master clutches
- Modulated slip clutches and drag brakes
- Hoist clutches and brakes
- Mining equipment clutches and brakes
- Fan clutches

COMPARISON TO BRONZE

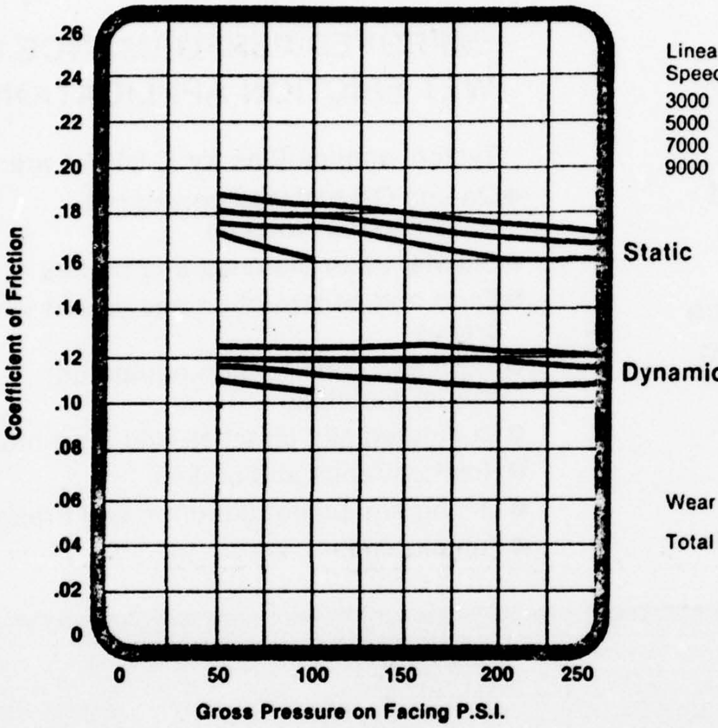
	C-6475-4	Sintered Bronze
Dynamic Friction	.11-.13	.05-.08
Static Friction	.17-.19	.08-.14
Engagement Quality	Good	Fair to Good
Energy Capacity	Excellent	Good
Durability	Excellent	Good
Resistant to Mating Plate Distortion	Very Good	Medium to High
Compatability to Oils	Good to Excellent	Fair to Good

NOTE: The data included in this brochure is typical of C-6475-4. However, performance characteristics will vary somewhat in different applications, oil grades, oil additives, flow rates, groove patterns.

TYPICAL C-6475-4 TEST DATA

TEST CONDITIONS

Pressure Speed Energy to Failure
One Active Surface Facing Size—11.250 O.D. x 8.789 I.D.
Grooving—Sunburst
Oil—Shell Hi-Base, SAE-30W
Oil Flow—1.0 G.P.M.
Inertia 0.842 lb-ft = sec²



LEGEND

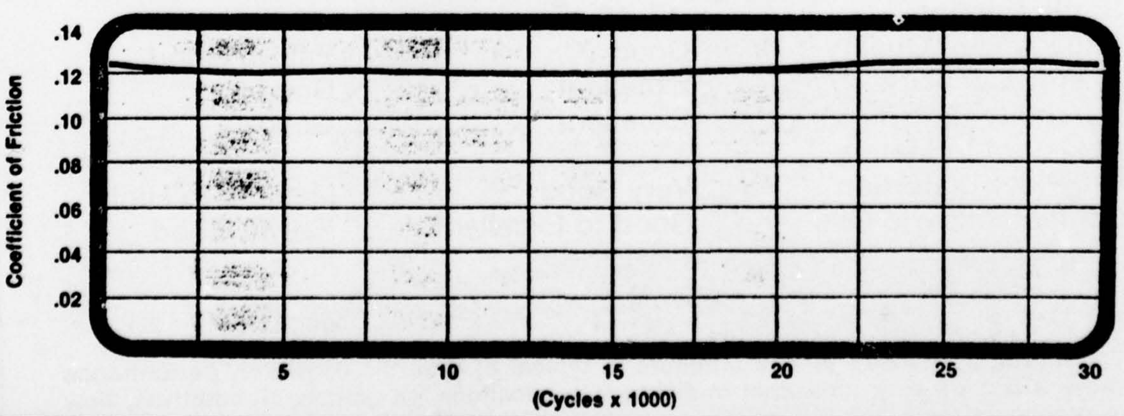
Linear Speed(Ft/Min)	Energy Ft-lbs/in²
3000	151
5000	441
7000	867
9000	1427

Wear @ 7000/250 .0005"

Total Wear .005"

DURABILITY TEST

480 ft-lbs/in², 4365 ft/min x .013 gal. oil/min/in²



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APPENDIX NO. 4

AN ANALYSIS OF AN ELECTRIC SHIP DRIVE
POWERED BY A GAS TURBINE

4

ELECTRONICS R&D DIVISION
ED 930

Report 78-1G1-SHIPS-R1

AN ANALYSIS OF AN ELECTRIC SHIP DRIVE POWERED BY A GAS TURBINE

Westinghouse Research Laboratories
1310 Beulah Road
Pittsburgh, Pennsylvania 15235

TABLE OF CONTENTS

I. INTRODUCTION

Recent developments of homopolar-type* d-c machines have led to consideration of this class of machines for naval-ship drives. The basic system which is studied in this report consists of a gas turbine driving a d-c generator which supplies power to a d-c motor which in turn drives the ship propeller. This is in contrast to the more standard drive comprising of a steam turbine which drives the propeller through a speed-reducing gear. This report is confined to the analysis and performance of the electric drive and makes no comparisons with alternate drives.

*Specifically segmented magnet machines.

II. BASIC MACHINERY LAYOUT

Figure 2.1 shows the basic layout of the machinery which is proposed for a destroyer. Each of the two propellers is driven by a motor which is in turn supplied by two parallel-connected generators each of which are driven by a gas turbine.

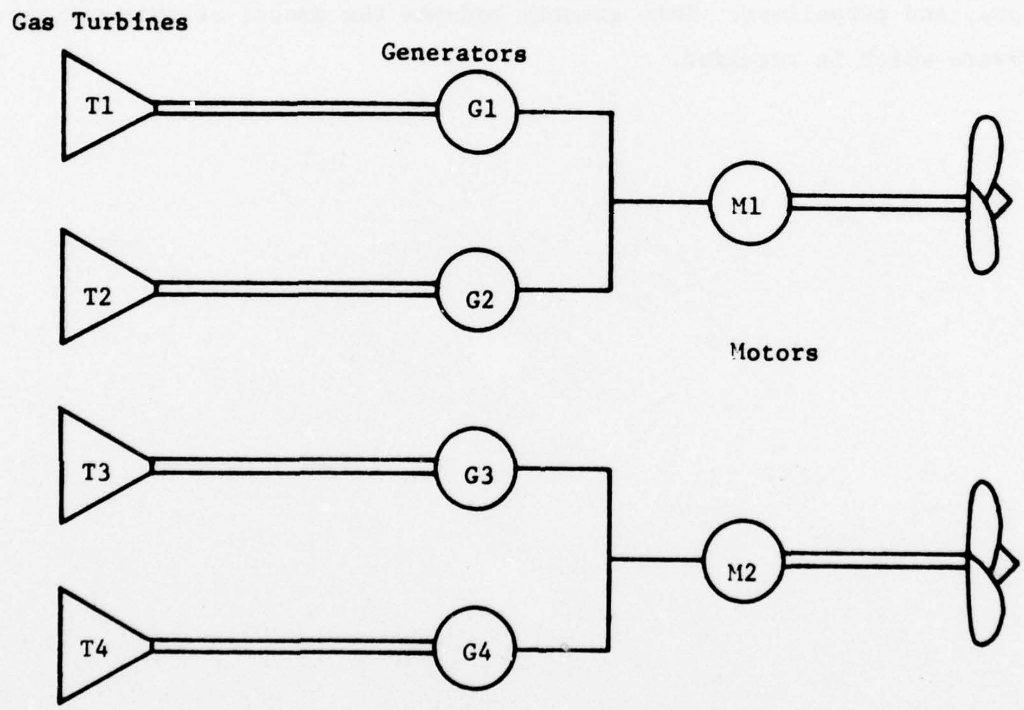

Figure 2.1. Arrangement of Machinery for Destroyer Propulsion System

The figure shows the so-called full-power configuration which goes from zero to 100% power of the system. However, for long-term

low-power application the system is to be reconfigured so that one turbine-generator set drives both motors connected in series. This configuration leads to lower overall fuel consumption but is limited to 25% power or less. Performance for these two cases is studied in detail.

The means for carrying out the study is an analog computer simulation in which the equations which represent the turbines, generators, motors, propellers, and the ship are simultaneously solved to yield the complete performance of the ship. When more than one turbine is operated, they all have the same input and output variables. For this reason it is necessary to provide a simulation for one turbine only. For exactly the same reason only one model is required for the generators, motors, and propellers. This greatly reduces the amount of computer hardware which is required.

III. THE CONTROL PROBLEM

Before getting into the details of the computer program an overview of the control problem will be given.

The basic control is a motor torque control which can easily be attained by operating the motors with fixed field current and controlling the armature current by varying the generator field current. This control is well suited to the ship drive for several reasons. First, it brings under direct control two critical physical parameters: the armature-circuit current and the shaft torque. Armature current is important to control not only because of the thermal limitations of the machines but also because of potentially destructive torques and forces which could result if the propeller were to become entangled with some foreign object. The alternative to torque control is motor speed control. With this type of control, in the event of a propeller entanglement the system would increase the generator field current and thereby the armature current and torque. Special means would have to be provided to sense and limit the armature current. On the other hand, if one were to lose a propeller or otherwise lose propeller torque, the speed control will limit the motor speed which is to our advantage. However, the torque control will increase the generator field (assuming field control is used) until saturation or other limiting occurs at which time the motor speed will no longer increase. Thus a self-limiting action results without additional expense. By considering these two extreme cases it is evident that armature current control is quite desirable.

One can effect control of the armature current by changing the generator flux or speed. Because the generator and turbine speed are the same, and because a turbine overspeed cannot be tolerated,

the safest thing to do is to run the turbine at fixed speed and vary the generator flux. This is entirely consistent with the limiting action desired in the event of loss of motor load.

It is a simple matter to control the turbine speed at a nearly fixed value by making the turbine fuel valve open in response to turbine speed droop. Thus the turbine will control itself to provide whatever fuel flow is required to maintain the speed nearly constant. Unfortunately, if it should be required for the generator to accept power, a negative turbine speed droop will result which will call for negative fuel flow. This is not a physically possible situation since zero is the minimum fuel flow, and the turbine can accept power only by accelerating its rotor and storing the energy as kinetic energy.

Consider now the case where the ship is being driven forward at some nominal speed. Let it be desired to operate the ship at a reduced speed. One can accomplish this by reducing the commanded torque to zero. This will result in the gradual slow down of the ship as a result of drag forces. On the other hand, if one is unwilling to wait until the natural drag on the ship slows it down, a negative torque might be commanded in which case the commanded motor torque and speed will be in opposite directions. This results in regeneration which invariably results in acceleration of the turbine.

As already mentioned, over-speeding of the turbine must be avoided. Therefore regeneration from the motor must be limited. The most conservative course of action is to arrange the control so that regeneration of power into the turbine is prevented by finding some other means of disposing of the regenerated energy. The opposite extreme to this is to let the turbine accelerate but pre-arrange the initial speed of the turbine and the energy to be absorbed so that an over-speed trip does not occur. This latter solution is very much a function of the numbers in the sense that the energy which must be absorbed may be completely inconsistent with energy absorbing

capability of the turbine-generator rotating inertia, and it may be necessary to find backup means such as a brake to absorb energy.

Further insight into the regeneration problem can be gained by considering the analog circuit for the ship mass, propeller, and motor shown in Fig. 3.1.

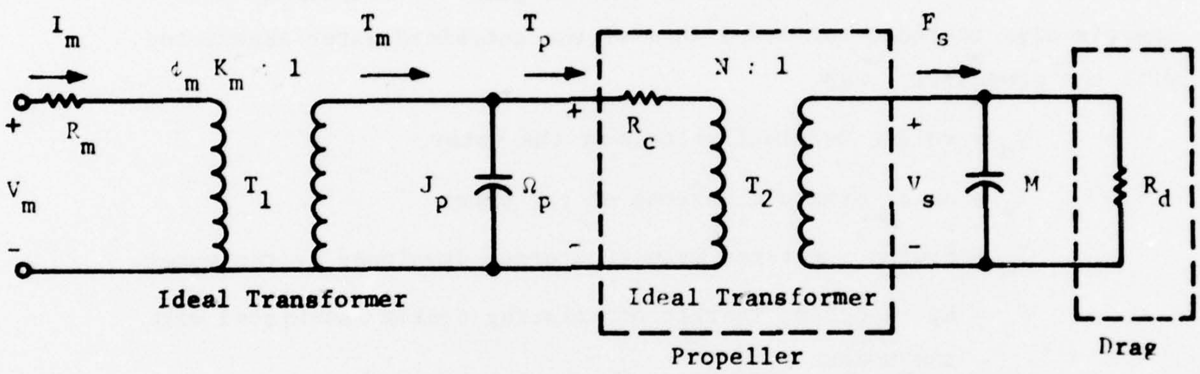

Figure 3.1. Approximate Linear Circuit Representing the Ship-drive System. Electrical Element Values are in Ohms and Farads.

In the figure let: V_s = m/sec, forward speed of the ship

M = Kg sec^2/m, mass of the ship

F_s = newtons, propeller thrust acting on the ship in the forward direction

R_d = m/(sec·newton), reciprocal drag resistance

Looking at the righthand side of Fig. 3.1, the current designated F_s is divided between the capacitor M and resistor R_d. The current flowing into M increases the voltage V_s while that flowing through R_d is required to sustain the voltage V_s. The differential equation relating F_s and V_s is

$$F_s = M \frac{dV_s}{dt} + \frac{V_s}{R_d} \tag{3.1}$$

which is recognized as the equation of motion for the ship and justifies that portion of the analog circuit. The resistance R_d is of course a nonlinear resistance and reflects the actual relationship between the drag force and the ship speed.

We now turn our attention to the left side of the circuit (Fig. 3.1) where we have the analog representation of the motor and the inertia of the motor armature, shaft and propeller. Presumably this inertia also includes the added mass of the entrained water associated with the propeller. Let

V_m = volts, terminal voltage of the motor.

I_m = amps, armature current of the motor

T_m = newton · meters, magnetic torque developed by the motor

J_p = Kg · sec^2/m, inertia of rotating system associated with the motor

T_p = newton · meters, torque which drives the propeller

ϕ_m = webers, machine flux

K_m = dimensionless machine constant

Ω_p = rad/sec, motor rotation speed

From Fig. 3.1 we find that

$$T_m = K_m \phi_m I_m \tag{3.2}$$

and

$$V_m - I_m R_m = K_m \phi_m \Omega_p \tag{3.3}$$

which may be recognized as the equation of a d-c motor. Also we find that

$$T_p = T_m - J_p \frac{d\Omega_p}{dt} \tag{3.4}$$

which we recognize as the equation of motion for the rotating mass associated with the motor armature.

In Fig. 3.1 the coupling between the left and right-hand members of the network is by means of the series resistance R_c and the ideal transformer with the turns ratio N:1. This is a somewhat crude attempt to represent the hydrodynamics of the propeller as it converts torque applied to the shaft, T_p, to thrust, F_s, on the ship. For our present purposes it is not important that this be an accurate representation.* However, we shall show that the form of the coupling network is at least plausible if not completely accurate. First of all, it is known that for any ship speed V_s there is a propeller speed for which both the propeller torque T_p and F_s are approximately zero. From the figure this propeller speed is clearly

$$\Omega_p = N\, V_s \tag{3.5}$$

Secondly, when the propeller is transmitting power, there are inefficiencies which in our circuit are represented by the loss in the resistor R_c.

We shall now use the circuit of Fig. 3.1 to enhance our understanding of the regeneration problem. Under steady-state operating conditions, say for $V_m > 0$, the power supplied at the terminals of the motors is spent through dissipation in resistors R_m, R_c and R_d. However, to get to steady-state in the first place it was necessary to supply additional energy to charge up capacitors J_p and M. This energy represents the kinetic energy of the propeller and the moving ship. If one wishes to further increase the ship speed it is necessary to increase V_m which will ultimately result in an increased voltage V_s. At no time will the instantaneous input power be negative and no threat of regeneration exists.

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*The representation in the computer simulation is accurate and includes all the nonlinearities.

On the other hand, suppose it is desired to reduce the ship speed. To do this the voltage V_s must be reduced by reducing V_m, the motor terminal voltage. There is great danger of regeneration now because the capacitor J_p is charged up to voltage Ω_p. If voltage V_m is reduced below the value $\phi_m K_m \Omega_p$, the current I_m will be negative and regeneration will occur. Because R_m, the armature resistance of the motor, is extremely small, only a few percent reduction in V_m will cause I_m to reverse. This fact is another reason why the basic control should be armature-current control and not motor speed. If we had speed control a small reduction in the speed reference will immediately reverse the armature current causing regeneration which is inherently dangerous to the gas turbine. With motor-torque or armature-current control the only thing one must guard against is applying a negative torque reference when the direction of rotation is positive or a positive torque reference when the direction of rotation is negative.

If we take the position that no regeneration is permitted, then to reduce speed, the best that can be done is to reduce the armature current I_m (and the motor torque T_m) to zero. This leaves the capacitors J_p and M charged up to the voltages Ω_p and V_s respectively which corresponds to the windmill propeller speed and the ship velocity.

As a result of the reciprocal ship drag resistance R_d, capacitor M will start to discharge which reduces voltage V_s which in turn permits J_p to discharge through R_c and the transformer T_2. Thus if one is willing to wait for the natural course of events to occur, the ship will slow down. To speed up the process it is essential that the motor be permitted to regenerate power.

Referring to Fig. 3.1, assume once again that the ship is in a steady-state ahead condition so that capacitors J_p and M are charged up. If we were to command a negative current I_m, this will hasten the discharge of capacitor J_p as well as capacitor M. Notice that the condition exists such that $I_m < 0$ and $\Omega_p > 0$, and the motor will regenerate. However, the negative current will ultimately completely

discharge J_p and commence to charge it up in the opposite direction so that voltage Ω_p as well as I_m will be less than zero. When this happens, the motor will cease regeneration and start to absorb energy.

If the commanded negative current is sufficiently large, the voltage Ω_p can be driven to zero while capacitor M remains essentially at voltage V_s. This is because the coupling resistor R_c tends to isolate the two capacitors. As Ω_p drops, the current T_p will go negative so that the rate of discharge of capacitor J_p will be retarded. It is clear that while Ω_p is greater than zero but decreasing, the regenerative motor power comes from two sources. The first is from the discharge of capacitor J_p and the second from the modest discharge of capacitor M as manifested by the negative value of T_p. If we were to discharge the capacitor J_p in zero time, by commanding I_m to have a negative impulse of the right value, then V_s will not decrease at all. Thus the regenerative energy will be just the initial energy stored in the capacitor J_p. That is

$$U_m = \frac{1}{2} J_p \Omega_p^2 \tag{3.6}$$

where U_m = joules, total energy regenerated.

This is the minimum possible value of the regenerated energy which results when the propeller is stopped or when Ω_p is driven to zero. Anything less than stopping the propeller instantaneously will result in a regenerated energy greater than this value. In general one can write

$$U_R \geq \frac{1}{2} J_p \Omega_p^2 \tag{3.7}$$

As already pointed out, after Ω_p is driven to zero, further continuation of the negative current results in Ω_p going negative and the motor starts to deliver mechanical power to the propeller. This power is absorbed partly in charging J_p up in the negative direction and in losses in the coupling resistor R_c. Capacitor M continues to

discharge only now at an increased rate since Ω_p is negative. As long as the current I_m is maintained at a value negative enough to hold Ω_p, the propeller speed, negative the motor will deliver mechanical power. Whenever a situation occurs where I_m, the motor current, and Ω_p, the propeller speed, have different algebraic signs, regeneration occurs; and the gas turbine is liable to overspeed.

With the previous background as an introduction, the control problem is to augment the basic torque or armature-current control system so as to protect the turbine from overspeeding in the presence of any arbitrary change in the torque reference without regards to either the ship speed or the direction of motor rotation.

IV. DETECTION OF INCIPIENT REGENERATION

The basic idea for protecting the gas turbine against overspeed is to continuously monitor the product of the motor speed Ω_p and the reference torque T_R. As long as this product is positive, the motor is supplying mechanical power, and no overspeed danger exists. However, the instant the product becomes negative then the turbine is endangered. The fact that the reference torque rather than the actual torque is considered provides the lead time necessary to take appropriate action. Regeneration is always the response to a change in the torque reference.

In the event that an incipient regeneration signal is obtained, the torque reference is automatically disconnected and a regeneration control cycle initiated which when completed reapplies the reference torque. The state of the system after the regeneration cycle will be such as to make it safe to reapply the reference signal.

The regeneration control cycle always consists of driving the speed of the motor, Ω_p, to zero without overspeeding the turbine and then reapplying the reference when it is safe. Thus it is a two-step cycle. The second step is rather elementary so it will be discussed first.

V. REGENERATION CYCLE - REAPPLICATION OF TORQUE REFERENCE

The speed of the motor is driven to zero by applying the appropriate torque which is a function of the ship speed. Thus as the ship speed changes with time so does the zero-speed torque.

When the ship speed is greater than zero, the torque required to stop the propeller is negative; and when the ship speed is less than zero, the stopping torque is positive. Figure 5.1 depicts this situation.

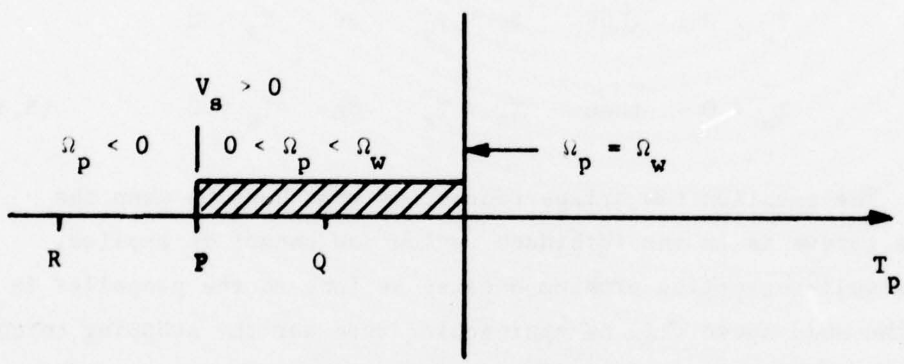

Figure 5.1 Prohibited Regions of Reference Torque for Zero Propeller Speed.

Suppose torque corresponding to point P stops the propeller for a certain positive speed of the ship. If a reference torque corresponding to point R is applied, the propeller will commence to rotate backwards in the same direction as the applied torque. On the other hand, suppose the reference torque happens to correspond to point Q. This is greater than the torque required to stop the propeller. Therefore, the propeller will start to rotate in the positive direction while the torque is negative — a regenerative situation which must be avoided.

If a positive reference torque is applied, then the speed and torque will both be positive which is nonregenerative. It is evident that reference torques between point P and the origin must not be applied. This is indicated by the cross-hatched box in Fig. 5.1.

One can carry out the same reasoning for the case where the stopping torque is positive ($V_s < 0$) and show that any reference torque between zero and the stopping torque cannot be applied without causing regeneration which would restart the regeneration control cycle.

Let T_s be the motor torque which stops the propeller and T_R the reference torque. Then the following conditions must be obtained to apply the reference torques. There are two cases:

$$T_s > 0 \quad \text{then} \quad T_R > T_s \quad \text{or} \quad T_R < 0$$

$$T_s < 0 \quad \text{then} \quad T_R < T_s \quad \text{or} \quad T_R > 0 \tag{5.1}$$

The question now arises concerning what happens when the reference torque is in the forbidden region and cannot be applied. This is a self-correcting problem because as long as the propeller is stopped the ship speed will be approaching zero and the stopping torque which is related to the ship speed will also approach zero. Thus in Fig. 5.1 the point P will move in time to the right toward the origin, and point Q will eventually be on the left of point P at which time the reference may be reapplied according to conditions in Eq. 5.1.

The whole problem of slowing the ship down from some positive speed V_s can be illustrated by a diagram similar to Fig. 5.1 which we show as Fig. 5.2 As before, the motor torque is representing the distance along the horizontal axis from the origin. Suppose the torque T_p corresponding to point S results in a sustained ship speed V_s and the propeller speed is Ω_s. Any applied torque between points 0 and S will result in ship deceleration since the applied torque is less than that required to sustain the speed V_s. However, the motor will supply

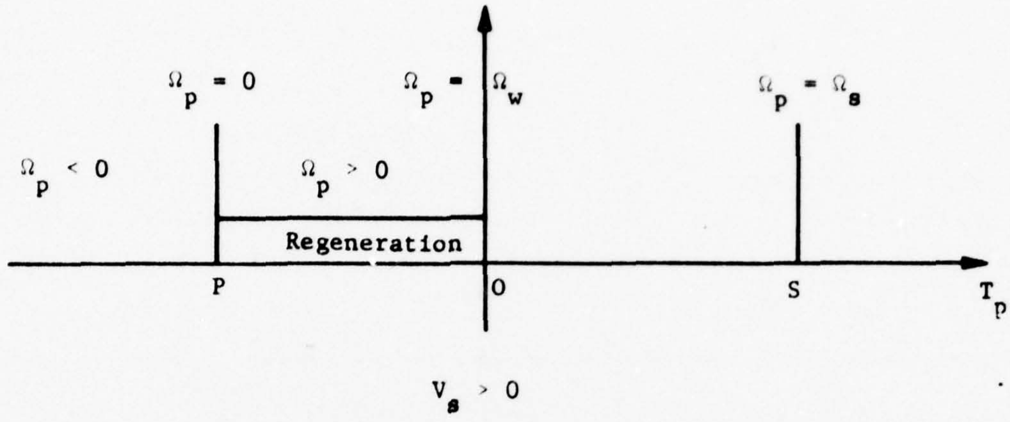

Figure 5.2. Diagram of Ship Slow-down Conditions for $V_s > 0$

positive power to the propeller. If the propeller torque is made equal to zero corresponding to point 0 on the T_p axis, the motor power will be zero, and the propeller will have the windmill rotational speed Ω_w.

If one desires to decelerate the ship faster than that corresponding to $T_p = 0$, then negative torque must be applied. The region $P < T_p < 0$ results in regeneration and must be avoided certainly for prolonged periods of operation. Furthermore, even if one passes through the band instantaneously there is a finite value of regeneration energy which was given by Eq. 3.6. Operation to the left of point P is non-regenerative and will result in rapid deceleration of the ship.

As has already been mentioned when a change in torque reference would result in operation in the regeneration band, the control system commences the regeneration control cycle. The first part of this cycle brings the operating point to P in Fig. 5.2 and then reapplies the torque reference when it is safe to do so.

VI. REGENERATION CYCLE - MOTOR STOPPING BY DYNAMIC BRAKING

A number of proposals have been made for means to bring the motor to a stop without causing overspeed of the turbine. It is possible to classify the various schemes according to amount of the energy which the turbine-generator rotating inertia is required to absorb during the process. For the most conservative schemes the turbine is completely protected in that no energy is permitted to be absorbed by the turbine. Other proposals require that turbine be first slowed down so that it can accept all of the regeneration energy, and still other schemes divide the regeneration energy between the turbine and a mechanical brake on the turbine shaft. The practicality must be assessed in terms of the hardware required for implementation and the risk to the turbine in event of failure. Obviously no scheme can be accepted as a candidate which can produce an overspeed trip under any circumstance.

We shall now consider the dynamic-braking scheme for stopping the motor. This scheme is the most conservative of all schemes because the turbine is required to absorb no energy. Thus its speed stays constant. The procedure is best explained by listing the sequential steps which must be carried out to bring the motor to a stop.

1. Disconnect the torque reference to cause the armature current to go to zero. A disconnected reference is the same as a zero reference.

2. When an armature current zero is detected, open the armature circuit.

3. When Step 2 is accomplished, provide voltage feedback around the generator and a zero voltage reference which will drive the generator voltage to zero.

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4. Reclose the armature circuit through a succession of paralleled resistors. The final step reduces the resistance to zero at which time the motor will have nearly zero speed since the generator voltage is controlled to be zero.

5. Convert the generator from voltage feedback to torque feedback when it is appropriate to reapply the torque reference according to the criteria given by Eqs. 5.1.

6. Reapply the torque reference.

Steps 1 and 2 essentially bring the motor to the windmill condition as discussed in relation to Fig. 5.2. By driving the armature current to zero, the armature circuit breaker can be opened without arcing which is desirable. In Step 3 the generator terminal voltage is driven to zero and held there by feedback control action. This prevents any regenerating power from being fed into the generator during the subsequent steps of the cycle.

After the terminal voltage of the generator has been zeroed, the speed of the motor is reduced to zero by forcing its terminal voltage to zero. Figure 6.1 is useful in understanding this action. If the ship speed $V_s > 0$, the torque-speed curve for the propeller

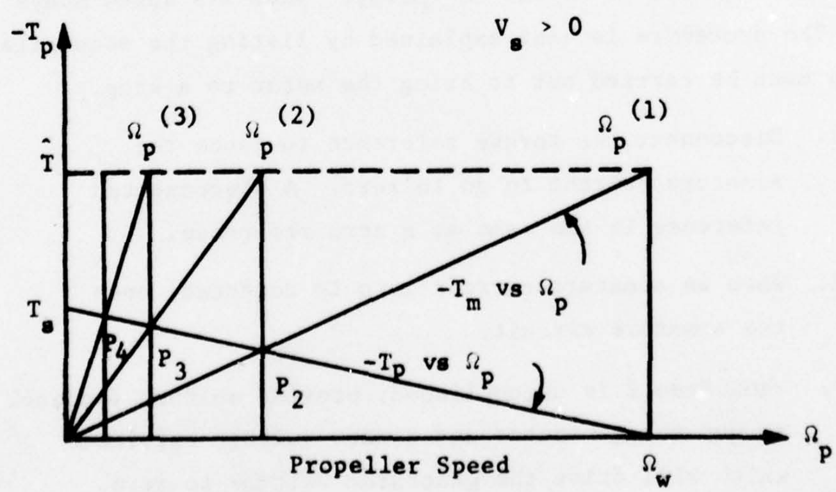

Figure 6.1. Diagram for Explaining Dynamic Braking.

(i.e., $-T_p$ vs. Ω_p) has a negative slope with an intercept on the Ω_p axis at the windmill speed Ω_w. This line is simply a plot of the equation

$$-T_p = (NV_s - \Omega_p)/R_c \tag{6.1}$$

which may be obtained directly from Fig. 3.1. Of course, this is only a rough approximation of the truth but serves adequately to demonstrate the stopping problem.

During Step 4 the motor-generator armature circuit is essentially that shown in Fig. 6.2. Consecutively switching in the resistors R_1, R_2, R_3, and R_4 causes the motor to slow down and come to a virtual stop when R_4 is switched on.

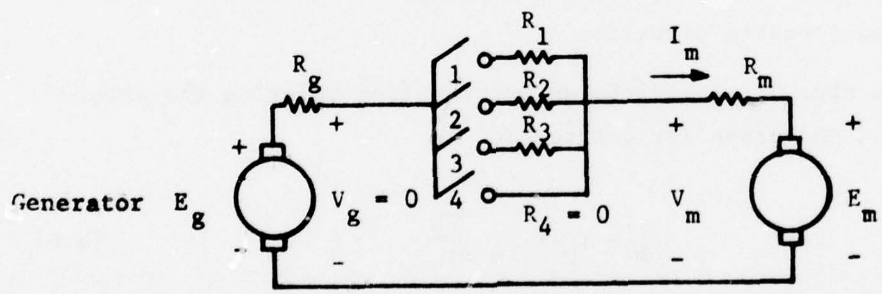

Figure 6.2 Armature Circuit During Motor Stopping

To see exactly how this occurs and to see what the problems are, the following analysis is necessary. Let R_a be the total armature resistance at any time. The minimum value of R_a is $R_m + R_g$ when R_4 is connected, and the maximum value is infinity when all switches are open.

$$I_m = -(E_m - E_g)/R_a \tag{6.2}$$

The generated voltage of the motor is

$$E_m = K_m \phi_m \Omega_p \tag{6.3}$$

and the motor torque is

$$T_m = K_m \phi_m I_m \tag{6.4}$$

Making use of 6.2 and 6.3, we find that the right member of 6.4 may be written

$$T_m = -\frac{K_m^{\,2} \phi_m^{\,2} \Omega_p}{R_a} + \frac{K_m \phi_m E_g}{R_a} \tag{6.5}$$

Since E_g is nearly zero because of the voltage feedback, the principal term contributing to the motor torque is proportional to the motor speed and in an opposite direction.

From Fig. 3.1 the differential equation relating the motor torque, T_m, and the propeller torque, T_p, is

$$T_m = T_p + J_p \frac{d\Omega_p}{dt} \tag{6.6}$$

Thus any difference between the motor and propeller torque results in acceleration of the motor, shaft and propeller inertias.

Suppose now we select a value of R_a corresponding to the closure of switch 1 in the armature circuit shown in Fig. 6.2. If we set $E_g = 0$ and plot $-T_m$ vs. Ω_p (Eq. 6.5) in Fig. 6.1, we obtain a straight line passing through the origin with the torque $\hat{T}$ when $\Omega_p = \Omega_w$. Since the propeller torque T_p is zero, when the propeller speed equals Ω_w, the entire motor torque, $T_m = -\hat{T}$, is available to decelerate the propeller. Thus the propeller speed decreases until point P_2 is reached at which time the motor and propeller torque balance each other and a stable equilibrium is reached.

To get any further reduction in speed, the armature circuit resistance must be still further reduced by closing switch 2. When this is done, the torque will increase and further deceleration will result. There is a definite limit on the permissible maximum motor torque which we shall assume to be $\hat{T}$. Obviously, the switched resistors must be determined so that this constraint is honored.

After the closure of switch 2, the new equilibrium point P_3 will be attained. One can continue the process indefinitely and further reduce the speed each time a switch is closed.

A potential problem with the above scheme is that the propeller can never be quite stopped no matter how many steps are used. After three steps one might be tempted to close switch 4 which in Fig. 6.2 reduces to zero all the external armature circuit resistance. Because $(R_m + R_g)$ is very small, this will in general lead to excessive torque and armature current. Usually more than three steps of resistance are required before it is safe to short out all the external armature resistance. As far as getting rid of the kinetic energy of the propeller and associated rotating masses, each step becomes less and less effective.

The dynamic braking procedure can be quantified as follows. Let the resistance steps be numbered 1, 2, 3, 4...L, and let i represent the i<u>th</u> step and L be the last step. Let the speed of the propeller at the instant the i<u>th</u> resistor is switched in be $\Omega_p^{(i)}$*. It is useful to express the propeller speed as a fraction of the windmill speed which we shall designate as

$$\omega_p^{(i)} = \Omega_p^{(i)}/\Omega_w \qquad (6.7$$

Also in Fig. 6.1 the torque which stops the propeller is designated as T_s.

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*Note the superscript is placed in parenthesis to distinguish it from an exponential.

The following recursion formula can be obtained for the successive equilibrium propeller speeds

$$\omega_p^{(i+1)} = \frac{\omega_p^{(i)} + \left(\frac{\hat{T}}{T_s} - 1\right)\frac{E_g}{E_m}}{\omega_p^{(i)} + \frac{\hat{T}}{T_s} - \frac{E_g}{E_m}} \tag{6.8}$$

where

$$E_m = K_m \phi_m \Omega_w \tag{6.9}$$

Also the armature resistance which results in the maximum allowable torque is

$$R_a^{(i)} = \frac{(K_m \phi_m \Omega_p^{(i)} - E_g)}{(\hat{T}/K_m \phi_m)} \tag{6.10}$$

Notice in Eq. 6.8 that the speed reduction obtainable depends strongly on the ratio of the peak allowable torque to the stopping torque ($\hat{T}/T_s$). As an example, suppose this ratio is 2 and $E_g = 0$, then Eq. 6.8 becomes

$$\omega_p^{(i+1)} = \omega_p^{(i)} \left[\frac{1}{2 + \omega_p^{(i)}}\right] \tag{6.11}$$

Successive values of $\omega_p^{(i)}$ are

i	1	2	3	4	5	6	7
ω_p	1.	.333	.143	.0667	.0323	.0159	.00813

Notice that with the assumed parameters it takes seven steps to get the speed less than 1% of the windmill value.

From Eq. 6.10 we see that the required armature resistance diminishes with $\Omega_p^{(i)}$. When $R_a^{(i)}$ becomes less than or equal to $R_g + R_m$, the minimum possible armature resistance, one can safely short circuit the remaining external armature resistance.

In the preceding analysis it is assumed that the equilibrium speed is attained before the next resistor is switched in. Actually the equilibrium speed is approached asymptotically according to the time constants which are determined by the dynamics of the system. If one neglects the armature inductance of the machines then the speed decay involves a single time constant which may be determined quite easily from the analog circuit of Fig. 3.1.

The speed change turns out to be so fast that for all practical purposes one can assume the ship speed, V_s, is fixed. For this reason the capacitor M in Fig. 3.1 can be replaced by a fixed voltage source with the value V_s. This makes the drag resistor R_d inconsequential as far as the decay of Ω_p is concerned. The switched-resistor network and the generator armature circuit must be connected to the motor terminals. If the above modifications and additions are made to the circuit of Fig. 3.1, the following circuit results.

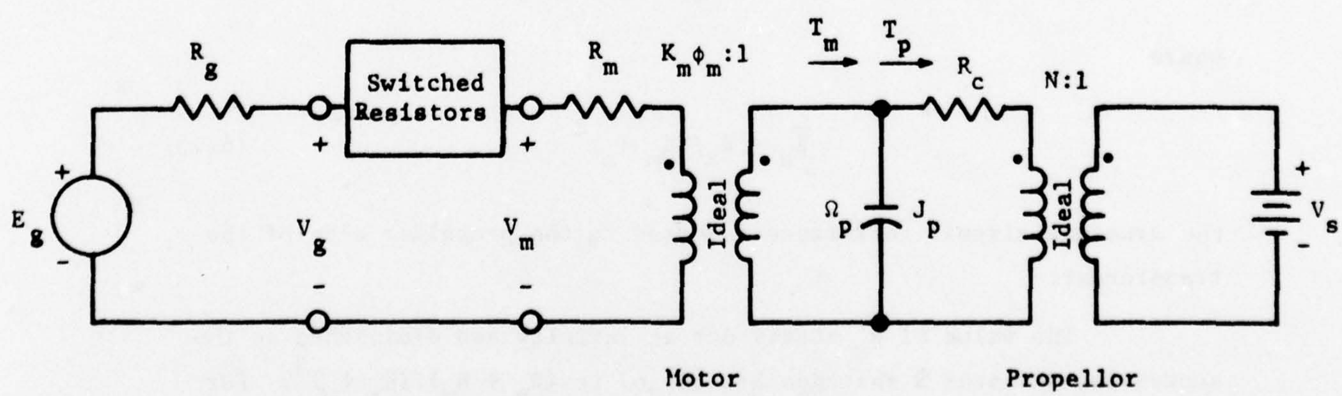

Figure 6.3. Circuit Representation of Dynamic Braking.

This circuit can be still further simplified by referring all impedance elements and voltage sources to the propeller. The

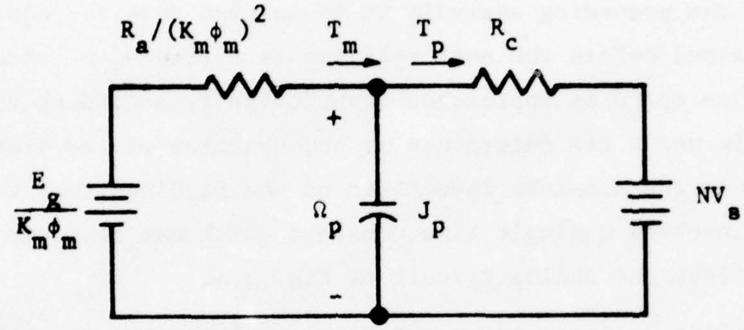

Figure 6.4. Dynamic Braking Circuit with the Ideal Transformers Eliminated.

circuit is now recognized as a simple R-C circuit with the time constant

$$\tau = \frac{R_c \overline{R}_a}{R_c + \overline{R}_a} J_p \tag{6.12}$$

where

$$\overline{R}_a = R_a/(K_m \phi_m)^2 \tag{6.13}$$

the armature circuit resistance referred to the propeller side of the transformer.

The value of $\overline{R}_a$ starts out at infinity and diminishes as the successive resistor S switches are closed to $(R_g + R_m)/(K_m \phi_m)^2$. For this reason the time constant of the circuit is reduced each time one of the switches is closed.

Fortunately, for the present ship drive even the longest time constant is considerably less than one second so that one can switch at nearly equilibrium speed without an excessive delay. In fact as will be seen from the dynamic performance records it is possible to stop the propeller from an initial speed of about 90 rpm in about one second.

An additional factor which has been left out of the present analysis is the armature-circuit inductance. This is of no consequence at all for the high resistance steps because the L/R ratio is so small. However, when the total armature resistance gets small, the inductive effect is significant. This influence is basically beneficial in that it reduces the initial switching current from the value that one would estimate based on the simple R-C circuit. As a result one can actually switch in a lower resistance than that determined by Eq. 6.10.

Finally all of the previous analyses have been based on a linear representation of the torque-speed characteristics of the propeller. Although this assumption yields reasonable results, for more accurate work it is necessary to use the actual torque-speed characteristics of the propeller. In Section XII-a the simulation is used to determine the switched resistor values and the voltage at which they should be switched. The method described not only takes into account the true torque-speed characteristics of the propeller but also includes the influence of the armature-circuit inductance.

Section X gives a complete description of the operation of the regenerative control when dynamic braking is used, and Section XII b and c give performance records which have been determined from the computer simulation.

VII. REGENERATION CYCLE - MOTOR STOPPING BY ACCELERATION OF THE TURBINE-GENERATOR

As mentioned in Section VI, an alternative to dynamic braking as a sink for the regenerated energy is the rotating inertia of the turbine generator.

In order for this method to be effective, it is necessary to reduce the speed of the turbine-generator shaft prior to the advent of motor regeneration. Unfortunately,it is precisely at this point where the method runs into difficulty. To discuss the problem, the diagram of Fig. 7.1 is useful. Here we show the plane on which are plotted curves of propeller torque vs. propeller speed for various ship speeds as the parameter. These characteristics are shown as straight lines only as a matter of convenience,and it is not implied that they are actually straight lines.

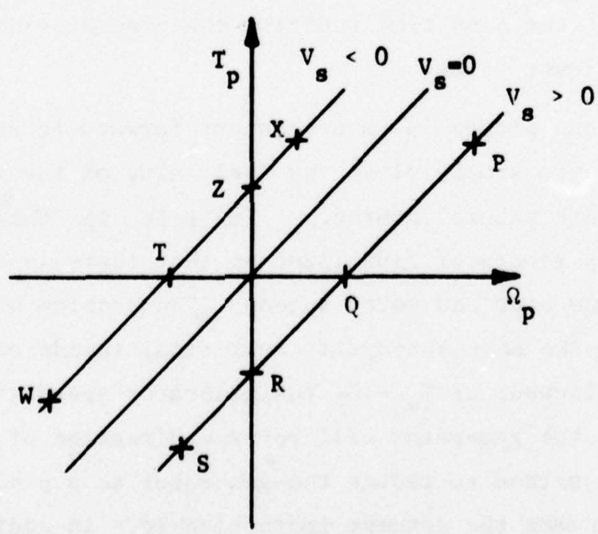

Figure 7.1. Propeller Torque vs. Propeller Speed for Fixed Ship Speeds.

When the ship speed, V_s, is zero, the characteristic must go through the origin. For $V_s > 0$ the intercept on the Ω_p axis will occur at a positive value of Ω_p, and for $V_s < 0$ the intercept will be at a negative value of Ω_p.

Steady-state operation is permitted only in the first and third quadrants while operation in the second and fourth quadrants are regenerative and can only be transitory.

Suppose the steady-state operation is at point P and it is desirable to change the operating point to S. This may be done by simply changing the torque reference from the value corresponding to point P to that corresponding to point S.

As has been explained in Section VI, because of the necessity to operate momentarily in quadrant four, it is necessary to provide regeneration control. The first step in this procedure is to remove the torque reference entirely so that the operation locus will move along the characteristic curve from point P to Q. Since in this Section we are considering the use the acceleration of the turbine-generator shaft as the sink for the regenerated energy, it is necessary to move from P to Q while at the same time reducing the generator speed to some predetermined lower value.

Various proposals have been put forward to accomplish this. One of which is to simply close the fuel value of the turbine and let things take their natural course. Implicit in this proposal is to hold the generator flux fixed so that there is a fixed ratio between the generator and motor speeds. The problem with this is that depending upon the ship speed, different final speeds of the generator will result. Indeed, if $V_s = 0$, the generator speed will go to zero; and if $V_s < 0$, the generator will reverse direction of rotation. The failure of the method to reduce the generator to a predetermined minimum speed seems to make the concept impracticable. In addition, if P is already at or nearly Q, the generator will not change speed at all.

The next proposal might be to not only close the fuel valve but also vary the generator field strength so as to provide some control over the ratio of generator to motor speed. This method fails for several reasons. The most obvious is the case when the ship speed, V_s, is zero. The propeller will stop and no matter how the ratio between generator and motor speed is adjusted the generator speed will also be zero. If $V_s > 0$ and the operating point Q were achieved, an increase in generator field flux would reduce the generator speed while a reduction in generator field flux will increase the speed. On the other hand, if the operation was at point T having previously been at W (generator flux would be negative), then to reduce the generator speed the flux would have to be made more negative (reduced) and to increase the generator speed the flux would have to be made more positive (increased). This is just the opposite of the control action required at point Q. Therefore, any control which involves changing the ratio by flux adjustment must change the sense of the feedback according to the sign of the flux and will completely fail when the ship speed is zero.

If the initial point of operation is at X, closing the fuel valve will in a matter of seconds reverse the generator rotation direction. How one could possibly manipulate the flux quickly enough to prevent this is not obvious.

Another proposal is to coordinate the speed of the generator so that at zero power the speed is at a minimum value and at full power the speed is at maximum. This would result in a minimum generator speed at all points on the Ω_p axis. There are two problems with this. First, any system for modifying the turbine speed would have to be much slower dynamically than the torque control system, so that a sudden change in the torque reference would result in operating point Q with the turbine-generator speed still at the value corresponding to point P. Furthermore, once this occurs there is no way to slow the turbine-generator shaft down without the aid of a separate brake because there is no electromagnetic torque on the generator rotor. Even if one were

to get to point Q at a reduced generator speed (say by very slowly reducing the torque reference), then when the regeneration takes place point R would result with the turbine-generator shaft going full speed. The subsequent application of a positive but almost zero torque reference would return the operating point to Q with the turbine-generator at full speed and no possibility to get it slowed down because there is no sink for the energy.

The ideas which have been discussed so far all use the propeller power as the sink for absorbing the kinetic energy of the turbine-generator when it is necessary to slow it down. Unfortunately, this energy sink is not always available when needed. Furthermore, the requirement of putting energy into the propeller is contradictory to the command to reduce the propeller torque to zero. As a consequence one is led to the conclusion that any practical system must have an independent means for slowing down the generator. That is, a means which is independent of the power which is flowing or is not flowing into the propeller. One such means is a mechanical brake on the turbine-generator shaft. This permits the generator to be slowed down at any arbitrary time simply by reducing its speed reference which will shut off the fuel and apply the brake.

The mechanical brake becomes the receptor for the kinetic energy of the turbine-generator inertia and by braking at a predetermined maximum torque the peak power requirement of the brake can be set at any desired level. Thus one can always get the generator slowed down as a preamble to the regeneration which will occur in going from Q to R or T to Z etc. Clearly the brake must be capable of absorbing all the energy released in slowing down the generator plus any additional regenerative energy in excess of that which will reaccelerate the turbine-generator shaft up to its maximum speed.* A system based on a mechanical brake which operates as indicated has been successfully simulated. Details of this system are described in Section XI, and computer records showing the performance are given in Sections XII d and e.

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* Practically even more energy absorption capability is required for reasons discussed in Sections XII d and e.

VIII. THE PER UNIT SYSTEMS FOR SIMULATING THE ELECTRIC MACHINES

The following sections of this report are concerned with the actual computer simulation of the ship, the propulsion machinery and its associated control. Often times it is convenient to carry out simulations in the so-called per unit system where the variables are expressed in percent of some predetermined base quantities. In such simulations the per unit variables are dimensionless, while the base quantities carry the dimensions.

In the present simulation only the electric machines are done in per unit variables. The simulation of the ship mechanics, the propeller and the gas turbine is done in actual physical variables which have dimensions. Although such a mixed simulation may seem inconsistent, it is really a great convenience since it permits consideration of different connections of the machines with a minimum amount of program changes and paper work.

One basic configuration of the machinery is known as the full-power configuration which is defined by Fig. 8.1. The reader should not

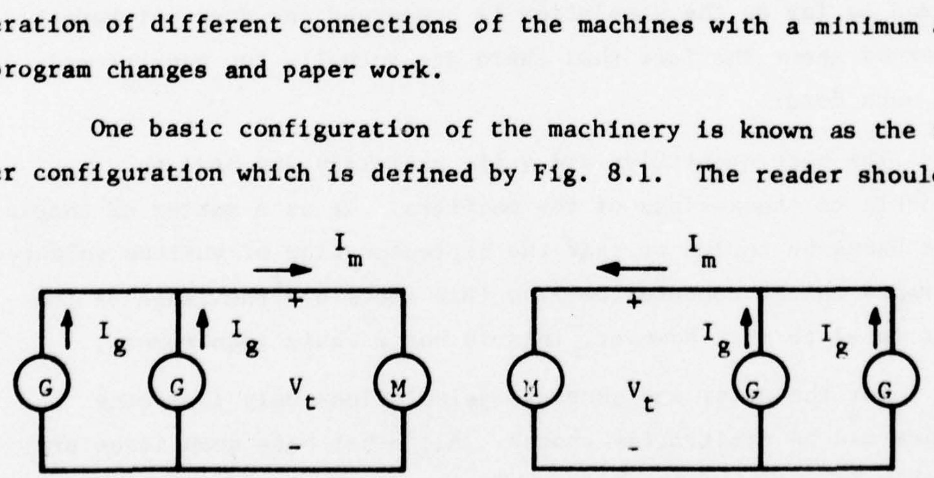

Figure 8.1. Full-Power Configuration of Machinery, Var I

think that because of the name of this arrangement of machinery it can only be operated at full power. It may operate at any power level from zero to full power, and may propel the ship either ahead or astern.

It is assumed in the simulation that all generators are doing exactly the same thing at the same time. Also the motors are operated under identical condition. As a result it is only necessary to simulate one of the four generators and one of the two motors.

The relation between the motor current and the generator current is seen to be from Fig. 8.1

$$I_m = 2\,I_g \tag{8.1}$$

If the motor base current is I, then Eq. 8.1 may be written

$$\frac{I_m}{I} = \frac{2\,I_g}{I} = \frac{I_g}{(I/2)} \tag{8.2}$$

The left member of Eq. 8.2 is the per unit motor current. By defining the base generator current to be one half of motor base current, then the right member of Eq. 8.2 is the per unit generator current. Consequently the per unit generator and motor armature current are equal, and as far as the simulation is concerned one does not have to be concerned about the fact that there are actually two generators driving each motor.

The base quantities are quite arbitrary and have no relationship to the ratings of the machines. It is a matter of convenience that the bases be chosen so that the representation of various voltages and currents on the computer be less than one since the range of the computer is -1 to +1. However, this is not a basic requirement.

For the motor and generator simulations only four base quantities can be arbitrarily chosen. All other base quantities are expressible in terms of these four bases. As the fundamental bases we have chosen voltage, current, time and speed. Hence for the full-power configuration one set of base quantities which have been used is as follows:

Base Set I: Full-Power Configuration, Var I

	Motor	Generator
Power	85.4×10^6 watts	42.7×10^6 watts
Energy	85.4×10^6 joules	42.7×10^6 joules
*Voltage	3300 volts	3300 volts
*Current	25,800 amps	12,900 amps
Resistance	.128 ohms	.256 ohms
Inductance	.128 henries	.256 henries
*Time	1 sec	1 sec
Torque	3.01×10^6 lb. ft.	$.750 \times 10^5$ lb. ft.
*Speed	200 rpm = 20.95 rad/sec	4000 rpm = 419 rad/sec
Damping	$.1438 \times 10^6$ lb. ft. sec	1.788×10^6 lb. ft. sec
Inertia	$.1438 \times 10^6$ lb. ft. sec^2	1.788×10^6 lb. ft. sec^2

*The fundamental base quantities are indicated by the asterisk.

There is a simple relationship between the various base values which comes from the physical relationships between the quantities. For example, base power is the product of the base voltage and current or torque times speed. Base energy is base power times base time. Base resistance is base voltage divided by base current.

To get base inductance, the considerations are slightly more complicated. The basic volt-ampere law followed by an inductance is

$$e = L \frac{di}{dt} \tag{8.3}$$

Let E = volts, base voltage

I = amperes, base current

T = sec, base time

Then Eq. 8.3 may be written

$$\frac{e}{E} = L\left(\frac{I}{ET}\right) \cdot \frac{d(i/I)}{d(t/T)} \tag{8.4}$$

If the base inductance is taken as ET/I, then the per unit volt-ampere relationship is exactly the same as that using volts, amps and seconds. Hence the base inductance must be

$$\frac{ET}{I} = \frac{3300 \times 1}{25,000} = .128 \text{ henries} \tag{8.5}$$

In a like manner one could find the base capacitance if desired.

In obtaining the base inductance,we had to make use of the base time which tends to be confusing. It is a matter of definition that the base quantity is the number by which one multiplies the computer representation of a physical quantity to obtain the actual physical quantity in the process being simulated. On the computer the time unit is one second. Hence, if one multiplies an elapsed time on the computer by the time base the elapsed time in the physical system is obtained. If we had selected the base time to be .01 sec, then one second on the computer is equivalent to .01 sec in the actual physical process which is simulated.

Of fundamental importance is the fact that the base quantities be chosen to preserve exactly the same equation between physical quantities in the per unit system. Otherwise, unnecessary constants will appear in the equations which can only lead to confusion. Another example of this comes about in the choice of the base torque of the motor. The base speed of 200 rpm (20.95 rad/sec) was chosen because the actual motor will never have a speed greater than that value. The base torque was chosen so that conservation of energy will hold for the motor in the per unit system. Let

E_m = volts, induced motor voltage
I_m = amps, motor armature current

ω_m = rad/sec, motor speed which causes E_m

T_m = newton-meters, motor torque in direction of ω_m caused by I_m.

Conservation of energy requires that

$$E_m I_m = \omega_m T_m \tag{8.6}$$

It is desirable to have this same expression hold in the per unit system. Let

E = volts, base voltage

I = amps, base current

Ω = rad/sec, base speed

τ = newton-meters, base torque

Equation 8.6 is unchanged when written in per unit

$$\left(\frac{E_m}{E}\right)\left(\frac{I_m}{I}\right) = \left(\frac{\omega_m}{\Omega}\right)\left(\frac{T_m}{\tau}\right) \tag{8.7}$$

provided

$$E\ I = \Omega\ \tau \tag{8.8}$$

This provides the basis for the choice of the base torque.

It should also be noted that the base quantities can be expressed in any convenient units. For example, the base speed is represented in rpm as well as radians/sec. By multiplying the per unit speed by the base speed in rpm, one gets the physical speed in rpm. If one wants the speed in rad/sec, then the speed base in rad/sec should be used.

Other sets of base quantities have been used in the course of this work. Another base set which has been used for the full-power configuration uses a lower base current and is defined as follows:

Base Set II: Full-Power Configuration, Var II (Reduced Current)

	Motor	Generator
Power	57.0×10^6 watts	28.5×10^6 watts
Energy	57.0×10^6 joules	28.5×10^6 joules
*Voltage	3300 volts	3300 volts
*Current	17,260 amps	8630 amps
Resistance	.1915 ohms	.382 ohms
Inductance	.1915 henries	.382 henries
*Time	1 sec	1 sec
Torque	2.004×10^6 lb. ft.	$.5 \times 10^5$ lb. ft.
*Speed	200 rpm = 20.95 rad/sec	4000 rpm = 419 rad/sec
Damping	$.0957 \times 10^6$ lb. ft. sec	1.193×10^2 lb. ft. sec
Inertia	$.0957 \times 10^6$ lb. ft. sec^2	1.193×10^2 lb. ft. sec^2

*The fundamental base quantities are indicated by the asterisk.

The so-called quarter-power configuration involves only one turbine generator set driving both the motors. Two variations of this have been studied so that two different sets of base quantities have been defined.

Figure 8.2 shows the first variation of the quarter-power configuration. In this case the motor and generator terminal voltages

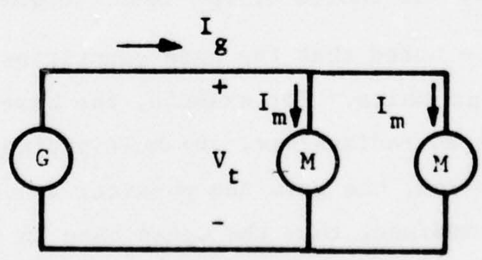

Figure 8.2. Quarter-Power Configuration, Var I, (Parallel Motors)

are the same so the same base voltage should be used. The relationship between generator current and motor current is

$$I_g = 2\, I_m \tag{8.9}$$

If I is the motor base current, then Eq. 8.9 may be written

$$\frac{I_g}{2I} = \frac{I_m}{I} \tag{8.10}$$

Consequently, by choosing the generator base current to be twice the motor base current, we have equality of the armature currents in the per unit system.

For this case the following base quantities have been chosen:

Base Set III: Quarter-Power Configuration, Var I (Parallel Motors)

	Motor	Generator
Power	57.0×10^6 watts	114×10^6 watts
Energy	57.0×10^6 joules	114×10^6 joules
*Voltage	3300 volts	3300 volts
*Current	17,260 amps	34,520 amps
Resistance	.1915 ohms	.0957 ohms
Inductance	.1915 henries	.0957 henries
*Time	1 sec	1 sec
Torque	2.004×10^6 lb. ft.	2.0×10^5 lb. ft.
*Speed	200 rpm = 20.95 rad/sec	4000 rpm = 419 rad/sec
Damping	$.0957 \times 10^6$ lb. ft. sec	4.77×10^2 lb. ft. sec
Inertia	$.0957 \times 10^6$ lb. ft. sec^2	4.77×10^2 lb. ft. sec^2

*The fundamental base quantities are indicated by the asterisk.

The next variation of the Quarter-Power Configuration places the two motors in series as shown in Fig. 8.3.

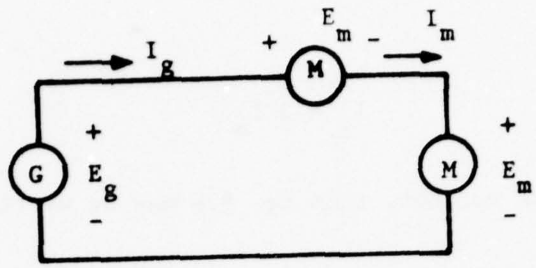

Figure 8.3. Quarter-Power Configuration, Var II, (Series Motors)

In this case the motor and generator armature currents are the same so a common base current is reasonable. The relationship between generator and motor terminal voltage is

$$E_g = 2\,E_m \tag{8.11}$$

If E is the base voltage of the motor, then

$$\frac{E_g}{2E} = \frac{E_m}{E} \tag{8.12}$$

and a generator base voltage equal to twice that of the motor would result in an equality in the per unit generator and motor voltage.

The following base quantities have been chosen for this configuration:

Base Set IV: Quarter-Power Configuration, Var II (Series Motors)

	Motor	Generator
Power	57.0×10^6 watts	114.0×10^6 watts
Energy	57.0×10^6 joules	114.0×10^6 joules
*Voltage	3300 volts	6600 volts
*Current	17,260 amps	17,260 amps
Resistance	.1915 ohms	.3825 ohms
Inductance	.1915 henries	.3825 henries
*Time	1 sec	1 sec
Torque	2.004×10^6 lb. ft.	2×10^5 lb. ft.
*Speed	200 rpm = 20.95 rad/sec	4000 rpm = 419 rad/sec
Damping	$.0957 \times 10^6$ lb. ft. sec	4.77×10^2 lb. ft. sec
Inertia	$.0957 \times 10^6$ lb. ft. sec^2	4.77×10^2 lb. ft. sec^2

*The fundamental base quantities are indicated by the asterisk.

The following physical constants and ratings of the electric machines have been used in this simulation:

Motor

$R_m = 2.36 \times 10^{-3}$ ohms, armature resistance

$L_m = 75 \times 10^{-6}$ henries, armature inductance

$J_{mp} = 54{,}300$ lb. ft. sec^2, motor-propeller inertia

Generator

$R_g = 1.755 \times 10^{-3}$ ohms, armature resistance

$L_g = 40 \times 10^{-6}$ henries, armature inductance

$\tau_f = .296$ sec, generator field time constant

$J_{tg} = 93.63$ lb. ft. sec^2, turbine-generator inertia

Machine Ratings

Motor	2000 volts	40,000 HP
	15,000 amperes	168 rpm
Generator	2000 volts	19,600 kW
	9800 amperes	3600 rpm

These numbers do not appear explicitly in the program blocks since the program requires constants in per unit. Hence, the constant must be divided by the corresponding base. Notice that the machine ratings are always less than the corresponding base quantities. This permits the machines to be operated, above their nameplate ratings without running out of the range of the computer.

IX. DESCRIPTION OF COMPUTER SIMULATION

The complete analog computer simulation of the ship drive system and its associated control is comprised of a series of functional blocks which in this particular case are numbered 1 to 23. Each block carries out a particular function and is interfaced with other blocks as required by the simulation. The block system of program representation provides a convenient method to document a very large program which otherwise would require an unmanageably large sheet of paper.

For our particular program the following blocks have been defined:

Block Number	Title
1	Gas Turbine
2	Generator Electrics & Mechanics
3	Motor Electrics & Mechanics
4	Ship Mechanics
5	Propeller Torque & Thrust
6	Generator Field Control
7	Interface to Dynamic Braking Coupling Network
8	Regeneration Control
9	Generator Friction Brake Control, Part I
10	Friction-Brake Servo Valve
11	Friction Brake Actuator
12	Turbine Speed Control
13	Generator Friction-Brake Power and Energy Measurement
14	Alternate Rate-Limited Torque-Reference Input Circuit

Block Number	Title
15	Generator Friction Brake, Part II
16	Propeller Power Measurement
17	Armature Relay Controls
18	Application of Friction Brake to Motor Shaft (not used)
19	Motor Power and Energy Measurement
20	Motor Friction-Brake Power and Energy Measurement
21	Motor-Generator Coupling Network
22	Ship Drag Correction Factor (not used)
23	Integrating Wattmeter

In the following paragraphs the various blocks will be explained. It will be assumed that the reader is basically familiar with analog computer equipment and symbols. There may be some conventions which are peculiar to this particular author's style, so a Glossary of Analog Computer Components is included at the end of this report.

Block 1, Gas Turbine

A rather simplified model of the gas turbine has been assumed which is based on the paper by Rubis and Peterson of NSRDC.* The simulation calculates the steady-state turbine torque for a given fuel flow, $\dot{w}_f$, and power turbine speed, Q_{GT}. Dynamics are included only to the extent that the rate at which the fuel flow can be increased is limited (see P26 [1],** and the decrease of fuel flow is governed by a simple exponential decay (see P35 [1]). It is assumed that the turbine cannot produce any negative torque. Hence the positive limiting on A66 [1].

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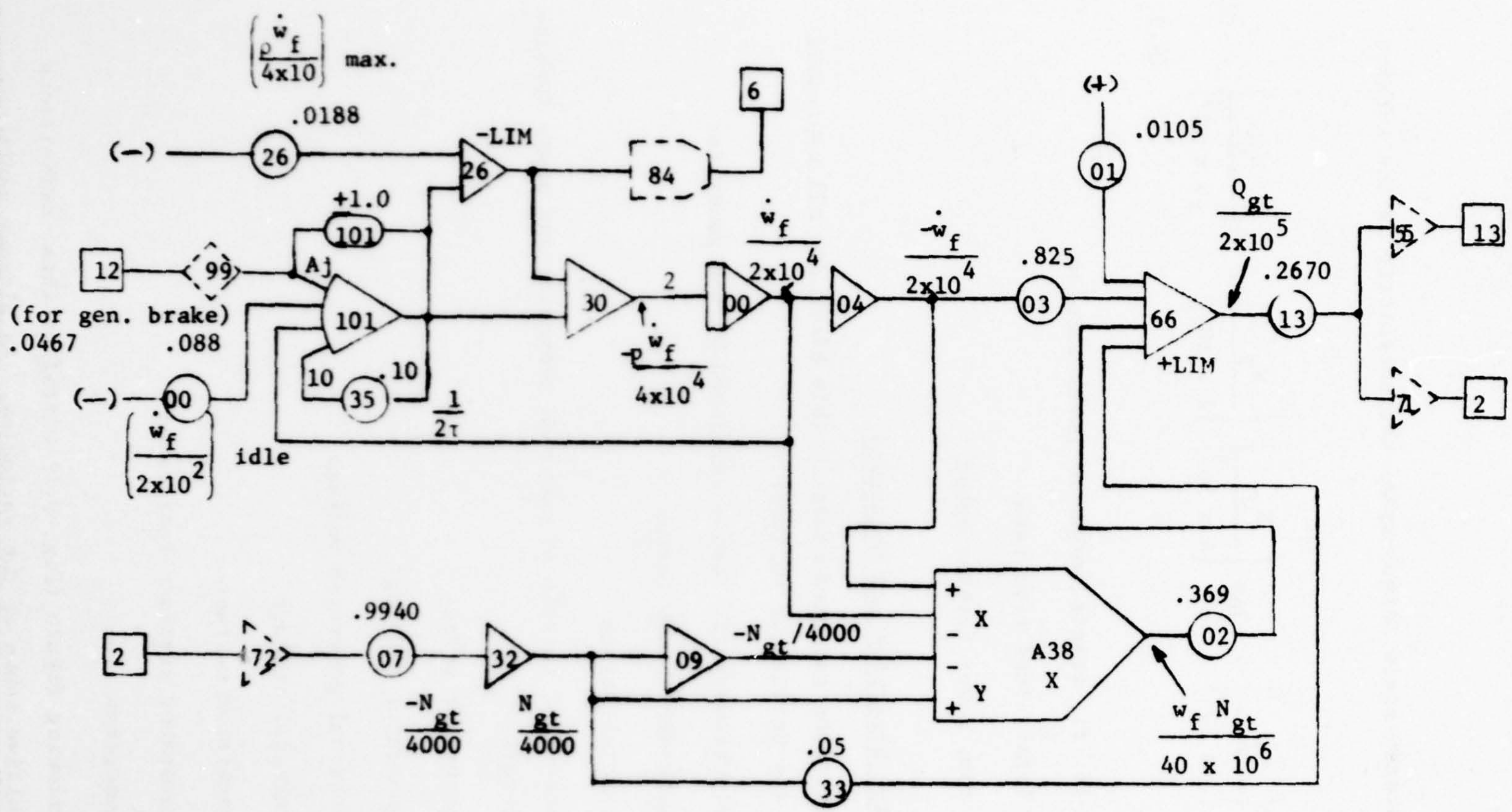
*C. J. Rubis, R. R. Peterson, Simulated Dynamics and Control of LM2500 Marine Gas Turbine Engine, Third Ship Control Systems Symposium, Ministry of Defense, Foxhill, Baltimore.

**This refers to Pot P26 located in Block 1.



BLOCK 1

Gas Turbine

The steady-state torque-speed characteristic of the turbine is given by

$$\frac{Q_{GT}}{2 \times 10^5} = .825 \left(\frac{\dot{w}_f}{2 \times 10^4}\right) - .369 \left(\frac{N_{GT}}{4 \times 10^3}\right) \left(\frac{\dot{w}_f}{2 \times 10^4}\right) - .05 \left(\frac{N_{GT}}{4 \times 10^3}\right) - .0105 \tag{9.1}$$

where Q_{GT} = lb. ft, output torque of power turbine

$\dot{w}_f$ = lb/hr, fuel flow rate

N_{GT} = rpm, power turbine speed

Block 2, Generator Electrics and Mechanics

The variables and parameters in this block are all expressed in per unit and are defined as follows:

τ_g = electromagnetic torque developed by the generator

τ_b = generator brake torque

τ_t = turbine torque

J_{tg} = moment of inertia of combined generator and power turbine rotors

ω_g = generator speed

B_g = generator damping

E_g = internal generated voltage

V_{tg} = terminal voltage

I_g = generator current

R_g = generator armature resistance

ϕ_g = generator flux

The following figure (Fig. 9.1) clarifies these definitions and shows the positive sense of the variables. As already mentioned,

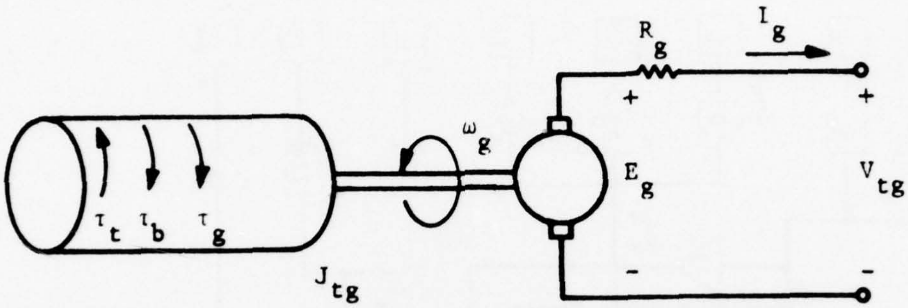


Figure 9.1. Electrical and Mechanical Representation of Generator.

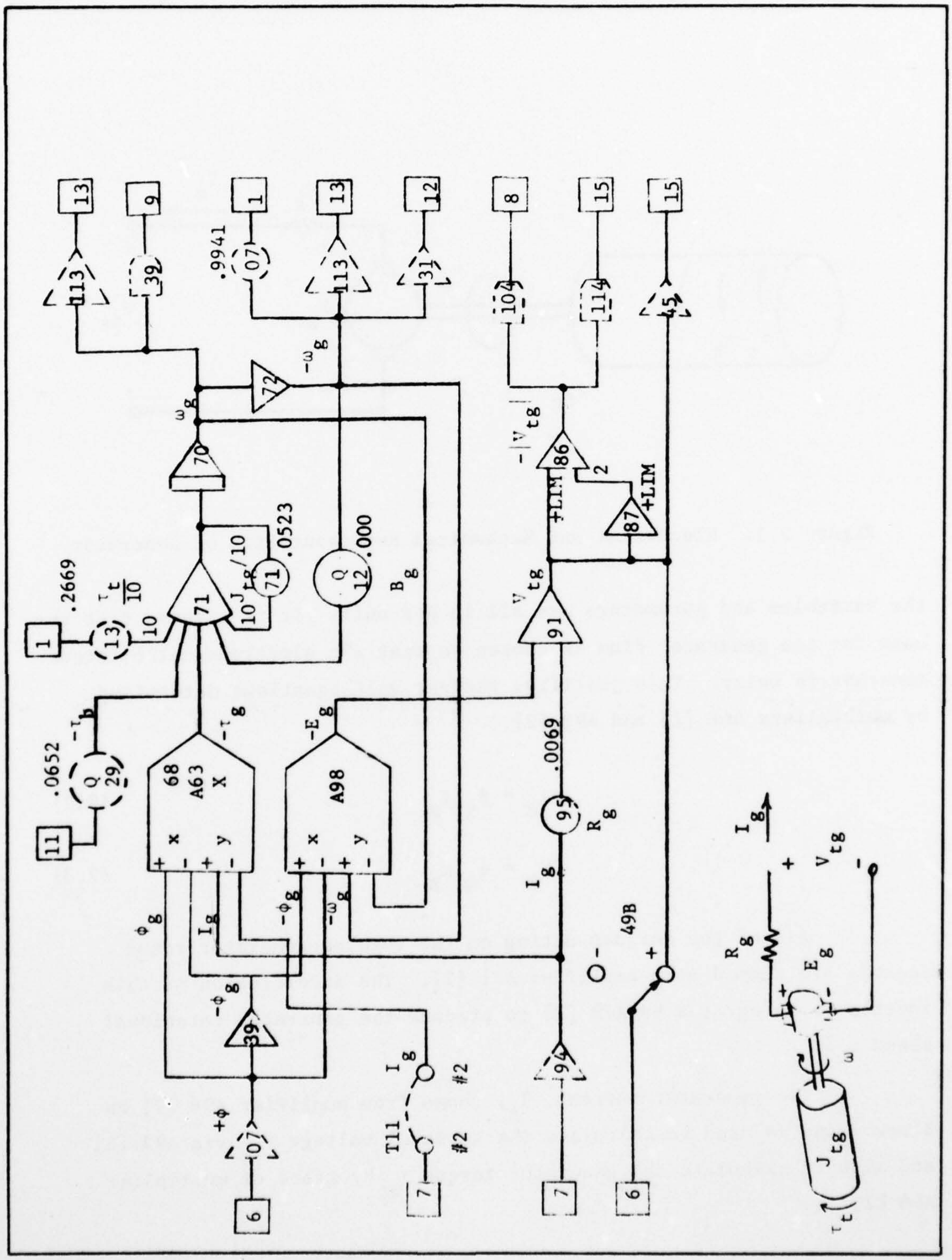
the variables and parameters are all in per unit. It is assumed that the base for the generator flux is chosen so that the electromagnetic torque constant is unity. This justifies the per unit equations determined by multipliers A68 [2] and A98 [2].

$$\tau_g = \phi_g I_g \tag{9.2}$$

$$E_g = \phi_g \omega_g \tag{9.3}$$

All of the torques acting on the turbine-generator rotor inertia are summed into amplifier A71 [2]. The acceleration of this inertia is integrated by A70 [2] to produce the generator rotational speed ω_g.

The generator current, I_g, comes from amplifier A94 [7] on Block 7 and is used to calculate the terminal voltage V_{tg} via A91 [2] and also to calculate the generator torque τ_g by means of multiplier A68 [2].



BLOCK 2

Generator

Block 3, Motor Electrics and Mechanics

The variables and parameters in this block are also all expressed in per unit and have the following definition:

τ_m = motor torque

τ_p = propeller torque

J_{mp} = combined moment of inertia of motor armature, shaft and propeller and entrained water

ω_m = motor speed

E_m = internal generated motor voltage

V_{tm} = terminal voltage of the motor

I_m = motor armature current

R_m = motor armature resistance

ϕ_m = motor field flux

Figure 9.2 clarifies these definitions and shows the positive sense of the variables.

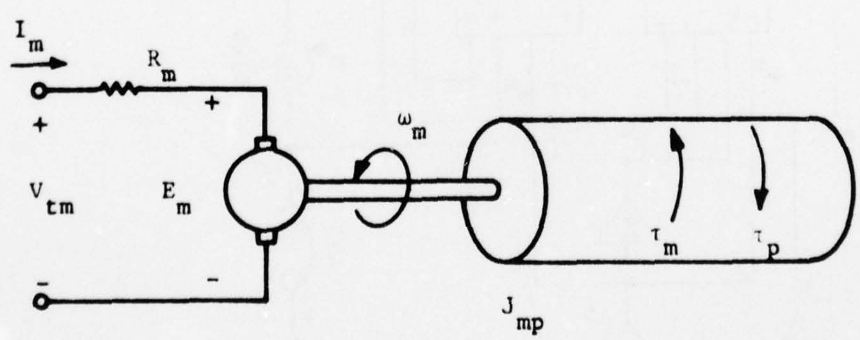
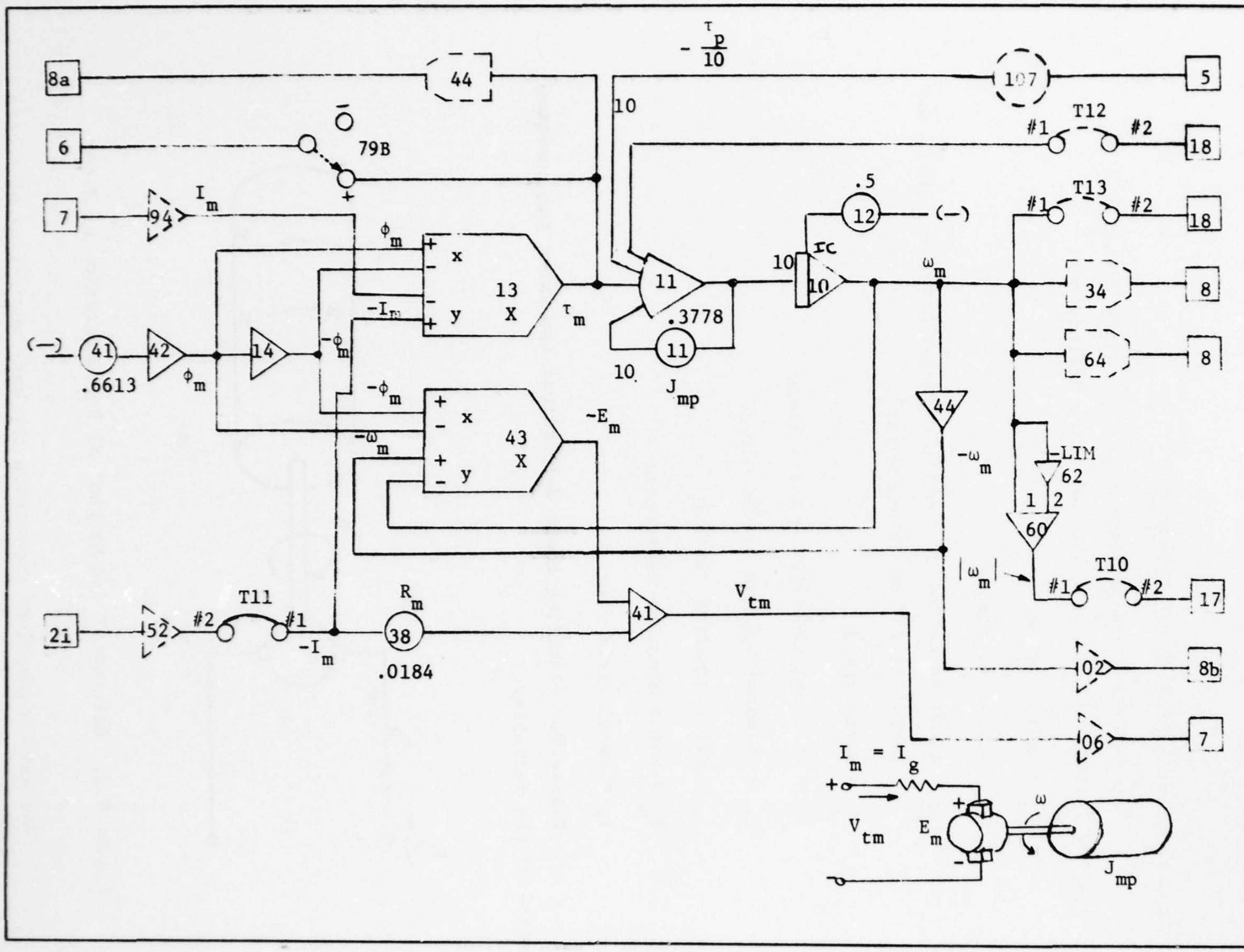


Figure 9.2. Electrical and Mechanical Representation of Motor.

The same assumptions concerning the base motor flux have been made as for the generator. The arrangement of the computer equipment is exactly the same as the generator and needs no further explanation.



BLOCK 3

Motor

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SEGMAG MACHINES FOR MARINE ELECTRICAL PROPULSION SYSTEMS. APPEN--ETC(U)
SEP 78 N00014-77-C-0307

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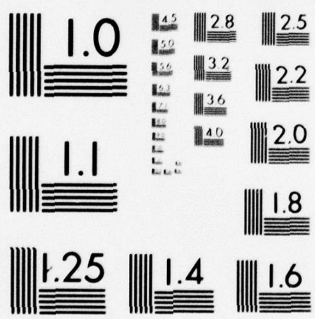

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Block 4, Ship Mechanics

In this block the following variables and parameters are used:

D_s = lbs, ship drag force

T = lbs, thrust of one of two propellers

M_s = lb. sec^2/ft, mass of the ship

V_s = ft/sec, velocity of the ship

X = feet, travel of the ship

The equation for the ship drag which is implemented is

$$D_s = 184\ V_s\ |V_s| \qquad (9.4)$$

This is calculated by multiplier A18 [4] and pot P19 [4]. The propeller thrust comes in via pot P75 [4] which among other things doubles the thrust because there are two identical propellers. Integrator A20 [4] integrates the ship acceleration to produce the ship velocity signal $V_s/60$.

To determine the ship travel, integrator A20 [4]* integrates the ship velocity. The mode of A20 [4]* is determined by register 2C [4] and is arranged so that the integration commences at the beginning of the regeneration cycle.

At one time during the simulation work there was a drag correction coefficient K_D which modified the square-law relationship of Eq. 9.4. This was implemented by means of trunks T16 and T17 with the circuitry shown in Block 22. When this feature was eliminated, trunks T16 and T17 were removed and pot P19 [4] set to apply the proper drag signal to A16 [4].

The positive sense of the various variables are given by Fig. 9.3.

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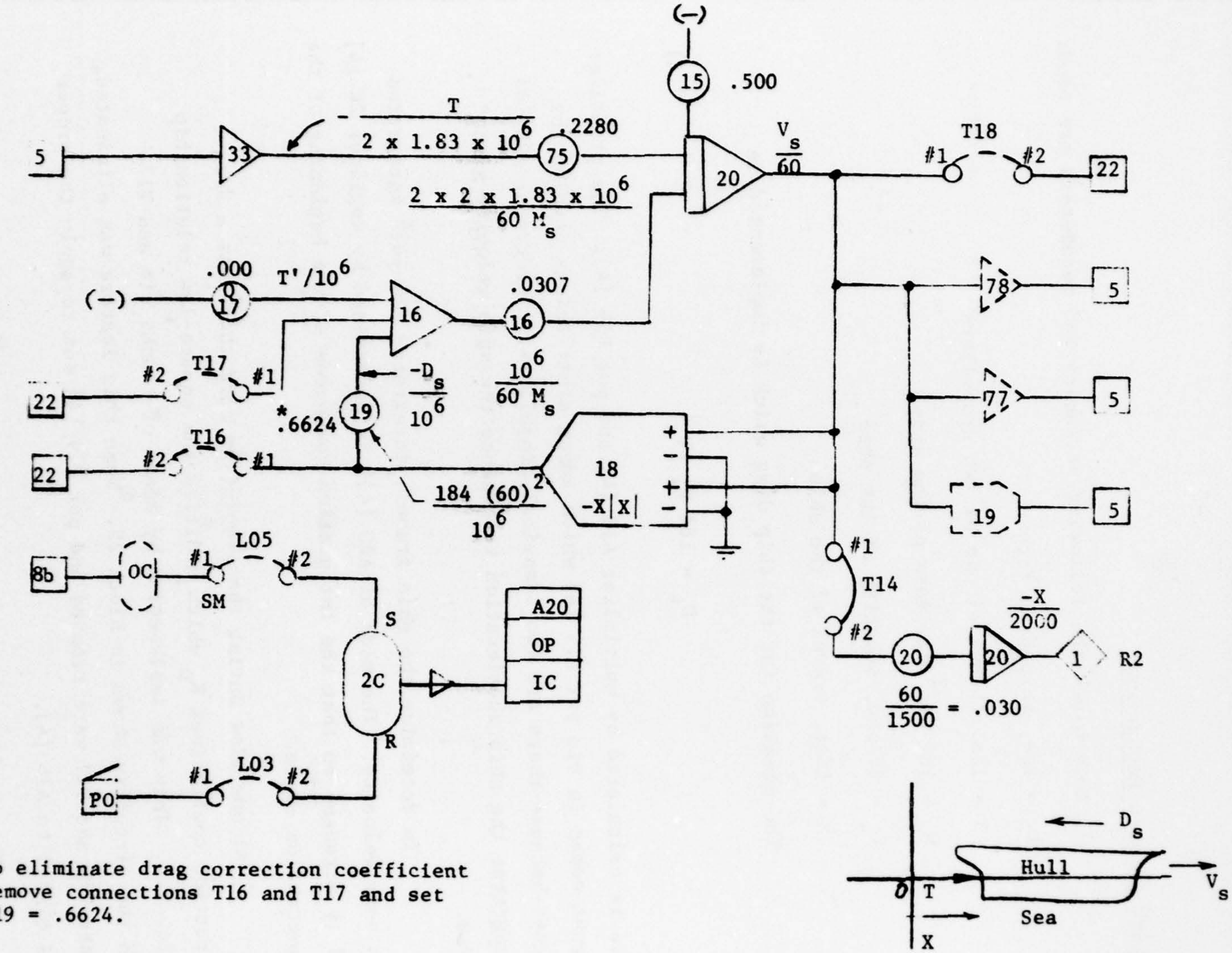
* This integrator is in Console 2 and should not be confused with integrator A20 [4] of the previous sentence.



*To eliminate drag correction coefficient remove connections T16 and T17 and set P19 = .6624.

BLOCK 4

Ship Drag

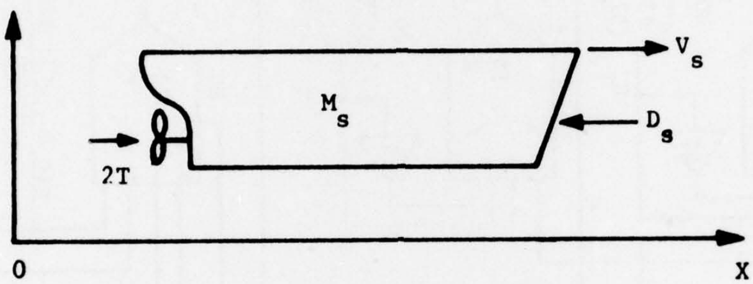


Figure 9.3. Definition of the Positive Sense of Forces Acting on the Ship Hull as Well as Its Velocity and Travel.

Block 5, Propeller Torque and Thrust

In this block the equations which determine the propeller thrust and torque are implemented. The input variables are:

$n = \omega_m$, per unit propeller speed relative to a base of 200 rpm and defined first in Block 3

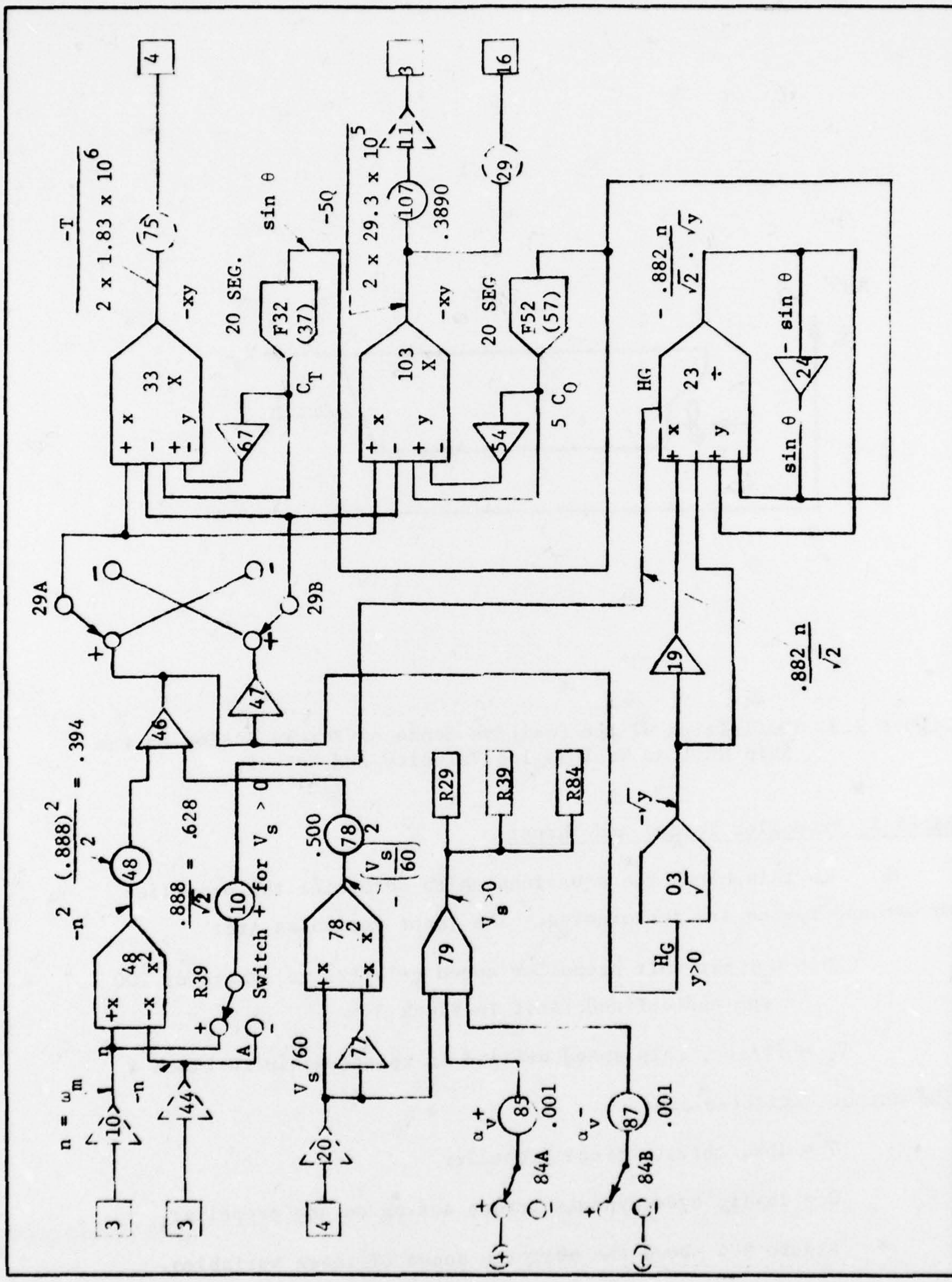
V_s = ft/sec, ship speed defined in relationship to Block 4

The output variables are:

T = lbs, thrust of one propeller

Q = lb·ft, hydrodynamic torque acting on one propeller

Figure 9.4 shows the positive sense of these variables.



BLOCK 5

Propeller

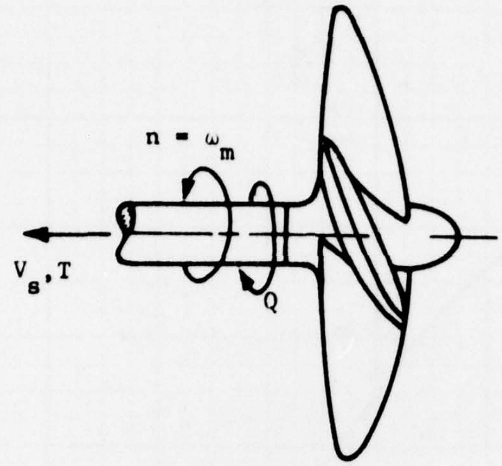


Figure 9.4. Positive Sense of Hydrodynamic Thrust and Torque Acting on the Propeller.

The equation for the propeller thrust is

$$T = 1.83 \times 10^6 \left[\left(\frac{V_s}{60}\right)^2 + (.888)^2\, n^2 \right] C_T \text{ lbs} \tag{9.5}$$

and the torque equation is

$$Q = 29.3 \times 10^6 \left[\left(\frac{V_s}{60}\right)^2 + (.888)^2\, n^2 \right] C_Q \text{ lb. ft.} \tag{9.6}$$

Constants C_T and C_Q are known as the thrust and torque coefficients and are function of the sine of an angle θ which is defined as

$$\sin\theta = .888n \Big/ \left(\left(\frac{V_s}{60}\right)^2 + (.888n)^2 \right)^{1/2} \tag{9.7}$$

Figures 9.5 and 9.6 show plots of C_T and C_Q as a function of sin θ. These functions are generated in the simulation by the use of function generators F32 [5] and F52 [5].

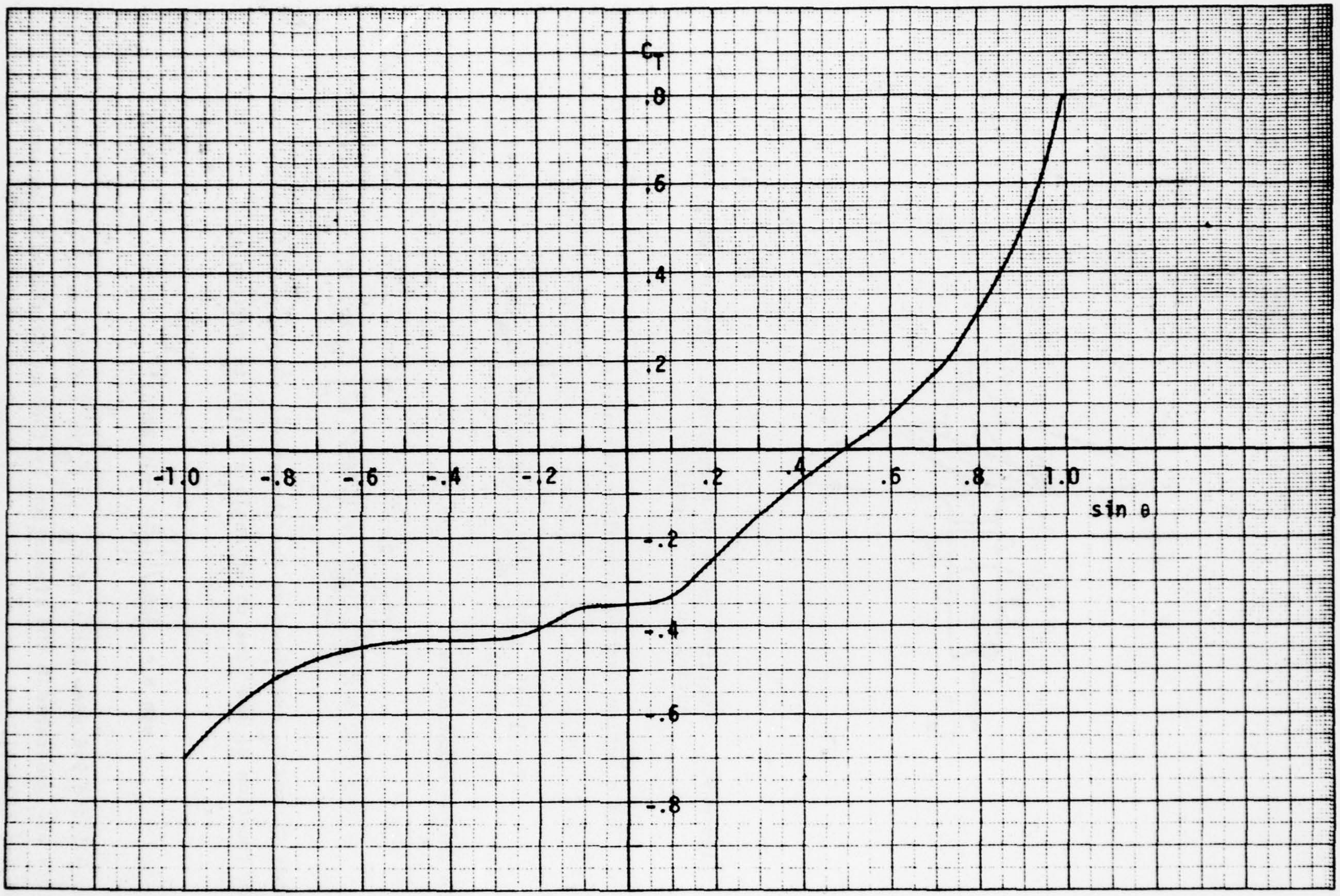


Figure 9.5. Propeller Thrust Coefficient.

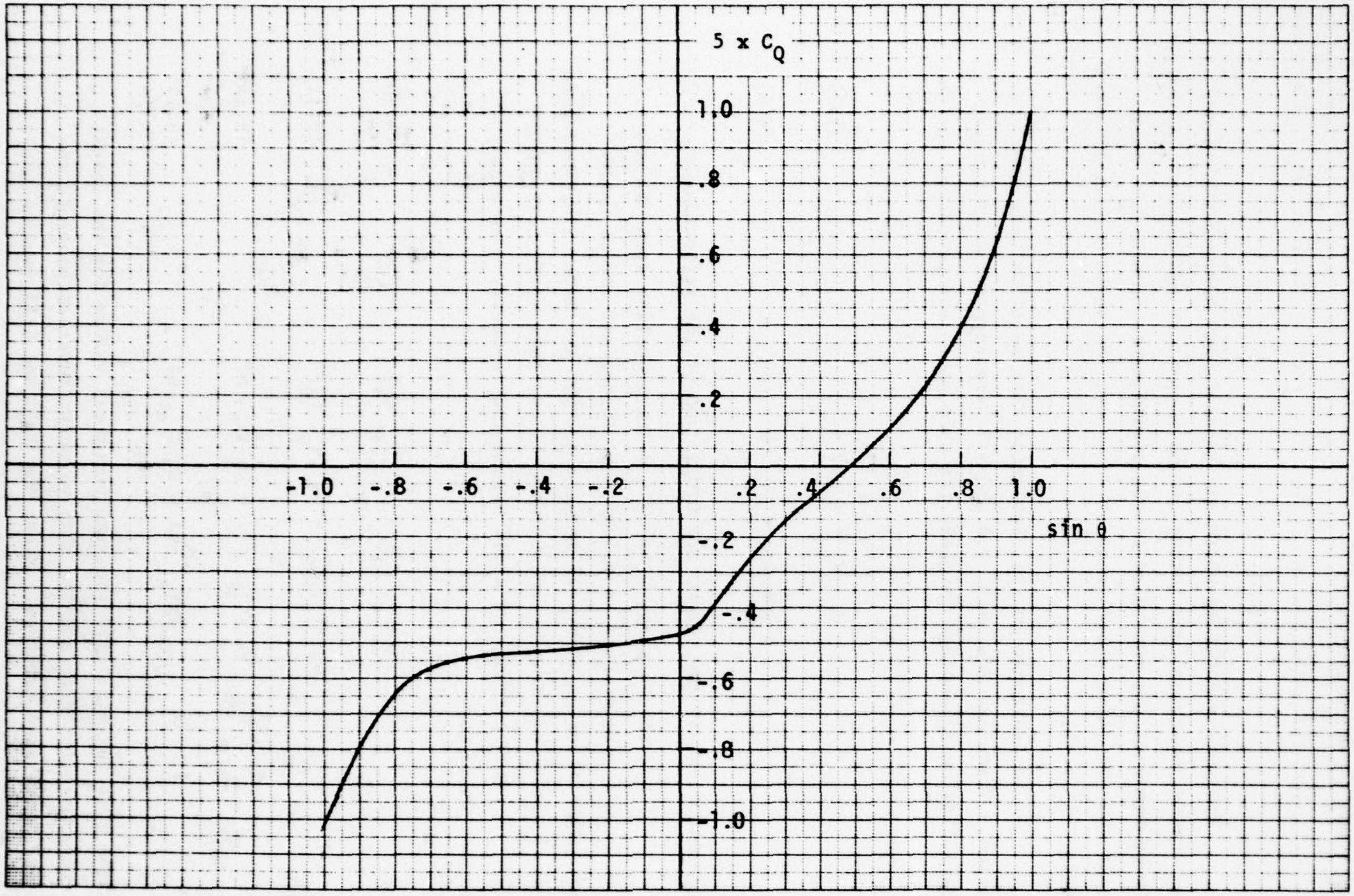


Figure 9.6. Propeller Torque Coefficient.

For ship velocities which are greater than zero, Eqs. 9.5 and 9.6 determine the thrust and torque for both positive and negative propeller speeds by means of the variation of the coefficients C_T and C_Q. Note that for the propeller speed range $-\infty < n < +\infty$, the value of $\sin \theta$ covers the range -1 to +1.

It is desirable in the simulation that negative ship speeds be permitted. Therefore Eqs. 9.5, 9.6 and 9.7 were adapted to this based on the following reasoning. Suppose the ship speed and propeller speeds are

$$V_s = V > 0 \qquad (9.8)$$

$$n = N \text{ where } -\infty < N < +\infty \qquad (9.9)$$

The propeller thrust and torque are T(V,N) and Q(V,N) respectively.

If now the ship speed is -V and the propeller speed is -N, then it is not unreasonable to assume that thrust and torque would reverse algebraic sign also. If it were not for the lack of hydrodynamic symmetry between the reverse and forward cases, this would certainly be true. For our purposes we shall assume that symmetry does exist so that we can write

$$T\,(-V_s,\ C_T) = -T\,(V_s,\ C_T) \qquad (9.10)$$

$$Q\,(-V_s,\ C_Q) = -Q\,(V_s,\ C_Q) \qquad (9.11)$$

$$C_T\,(-V_s,\ -n) = C_T\,(V_s,\ n) \qquad (9.12)$$

$$C_Q\,(-V_s,\ -n) = C_Q\,(V_s,\ n) \qquad (9.13)$$

Equations 9.12 and 9.13 give the same numerical values for the thrust and torque coefficients when the ship velocity reverses provided the propeller speed also reverses. Equations 9.10 and 9.11 reverse the

algebraic sign of the thrust and torque when the sign of the ship velocity is reversed and the thrust and torque coefficients remain unchanged.

In Block 5 implementation of these conditions is by Relays R29 and R39.

A special case of particular interest occurs when the ship speed is near zero while the propeller speed is held fixed, say at some positive value. From physical considerations the torque and thrust must be continuous at $V_s = 0$. Using the proposed scheme for handling negative ship speed, this can only happen if C_T has the same value when $\sin\theta = +1$ as when $\sin\theta = -1$. Inspection of Fig. 9.5 shows this not to be quite true. Hence there is a discontinuity in the propeller thrust when V_s goes through zero.

On the other hand, the torque coefficient C_Q does have the same value when $\sin\theta = 1$ and when $\sin\theta = -1$, and the torque is continuous when V_s goes through zero.

This writer has yet to see a satisfactory explanation of the thrust discontinuity. One of the off shoots of this problem is the fact that the relays which are to change the thrust and torque equations can get into a limited cycle oscillation condition at $V_s = 0$. To overcome this problem, it is necessary to introduce some hysteresis in the switching characteristics.

This is implemented by relay R84 [5] and pots P85 [5] and P87 [5] which bias comparator 79 [5]. The net effect is that if the velocity is negative and going positive it must reach the value +.001 before the switching occurs. If the velocity is positive and going negative it must reach the value -.001 before the switching occurs.

Block 6, Generator Field Control

Control of the armature current is by means of the generator field. In this simulation no allowance is made for saturation. Therefore it is assumed that the flux buildup to its final value is according to the time constant τ_f of the field circuit. The output amplifier A12 [6] is the generator field flux and P52 [6] sets the time constant for field changes. Amplifier A50 [6] is the input amplifier for the flux reference which has both integral and proportional components. Pot Q24 [6] supplies the proportional component while integrator A15 [6] cascaded with A74 [6] provides the integral component.

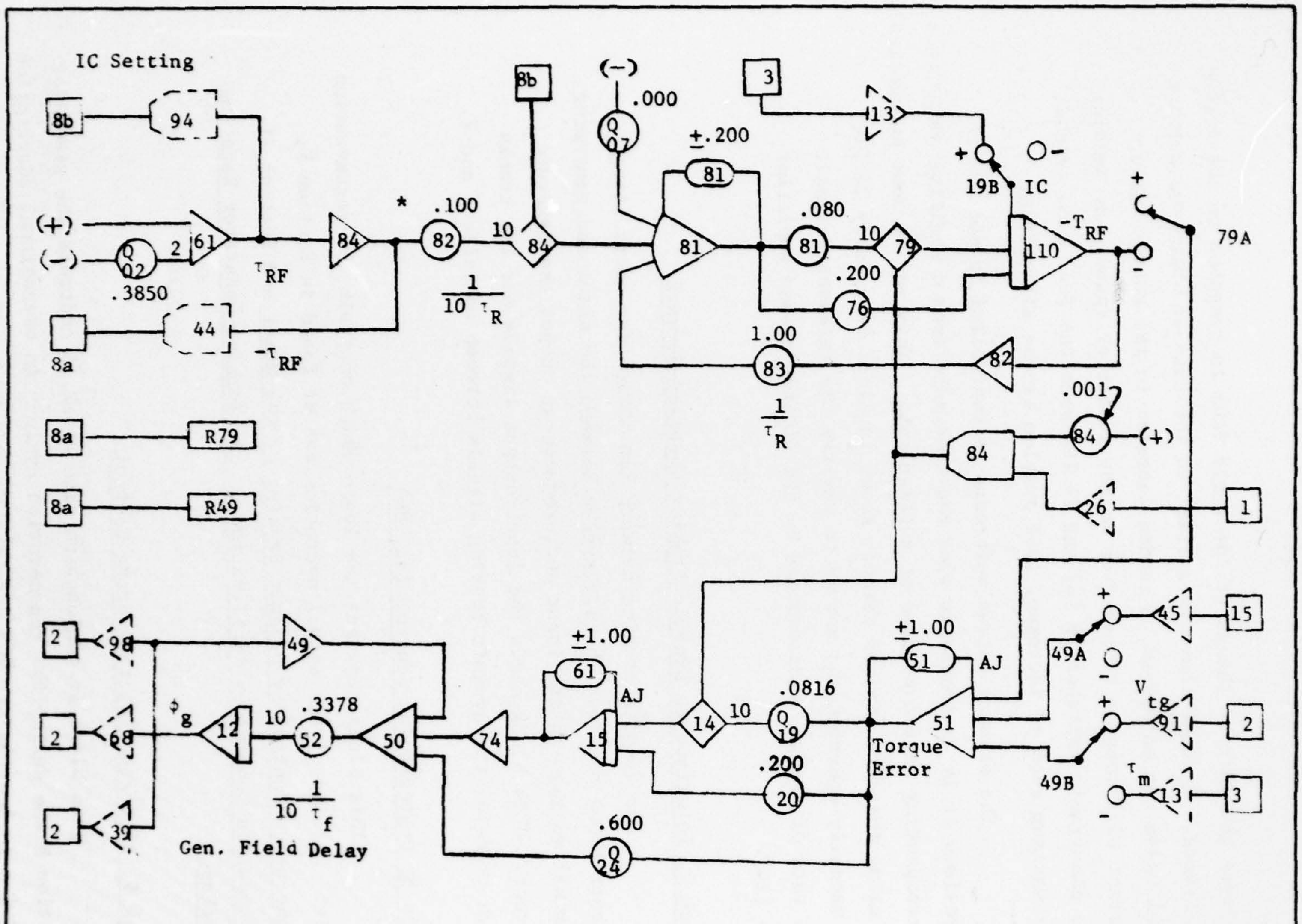
Amplifer A51 [6] supplies the error signal which may be a motor torque error if torque feedback is used or a terminal voltage error if voltage feedback is operable. The feedback signal is supplied to A51 [6] by relay 49B [6]. When the relay is low or in the negative position, the feedback signal is the motor torque τ_m. The positive relay position results in the generator terminal voltage feedback.

Relay 49A [6] provides the voltage reference, and is connected simultaneously with the voltage feedback signal. Relay 79A [6] connects the secondary torque reference τ_{RF}' which is supplied by integrator A110 [6].

The primary torque reference τ_{RF} appears at amplifier A61 [6]. This signal drives the circuit composed primarily of amplifiers A81 [6], A82 [6] and integrator A110 [6] which provides a simple time delay with the time constant τ_R plus rate limiting provided by the limiter around A81 [6]. This circuit prevents step functions from being applied to A51 [6].

Electron switch 84 [6] is used to disconnect the torque reference during the regeneration cycle. This causes the motor torque to go to zero since effectively a zero torque reference is applied.

Electron switches 79 [6] and 14 [6] when energized remove a large portion of the drive to integrator A110 [6] and A115 [6]. This



*See Block 14 for Alternate Input Circuit.

BLOCK 6

Generator Field Control

reduces the rate of change of the field flux in response to the torque reference. Because there is a limit to the rate at which the turbine fuel valve can be opened, a sudden increase in the motor armature current will cause a severe drop in the generator speed. By opening the electronic switches 79 [6] and 14 [6] when the fuel flow reaches its maximum rate of increase, this problem can be alleviated.

The primary torque reference is controlled by pot Q02 [6]. Sometimes it is desirable to slew the reference from a positive value to a corresponding negative value at a fixed rate. This may be done automatically by using the rate limited circuit shown in Block 14. Relay 24 [14] is manually operated and serves to reverse the reference signal. The rate of change is determined by the limiter around amplifier A25 [14].

Block 7, Interface to Dynamic Braking Coupling Network

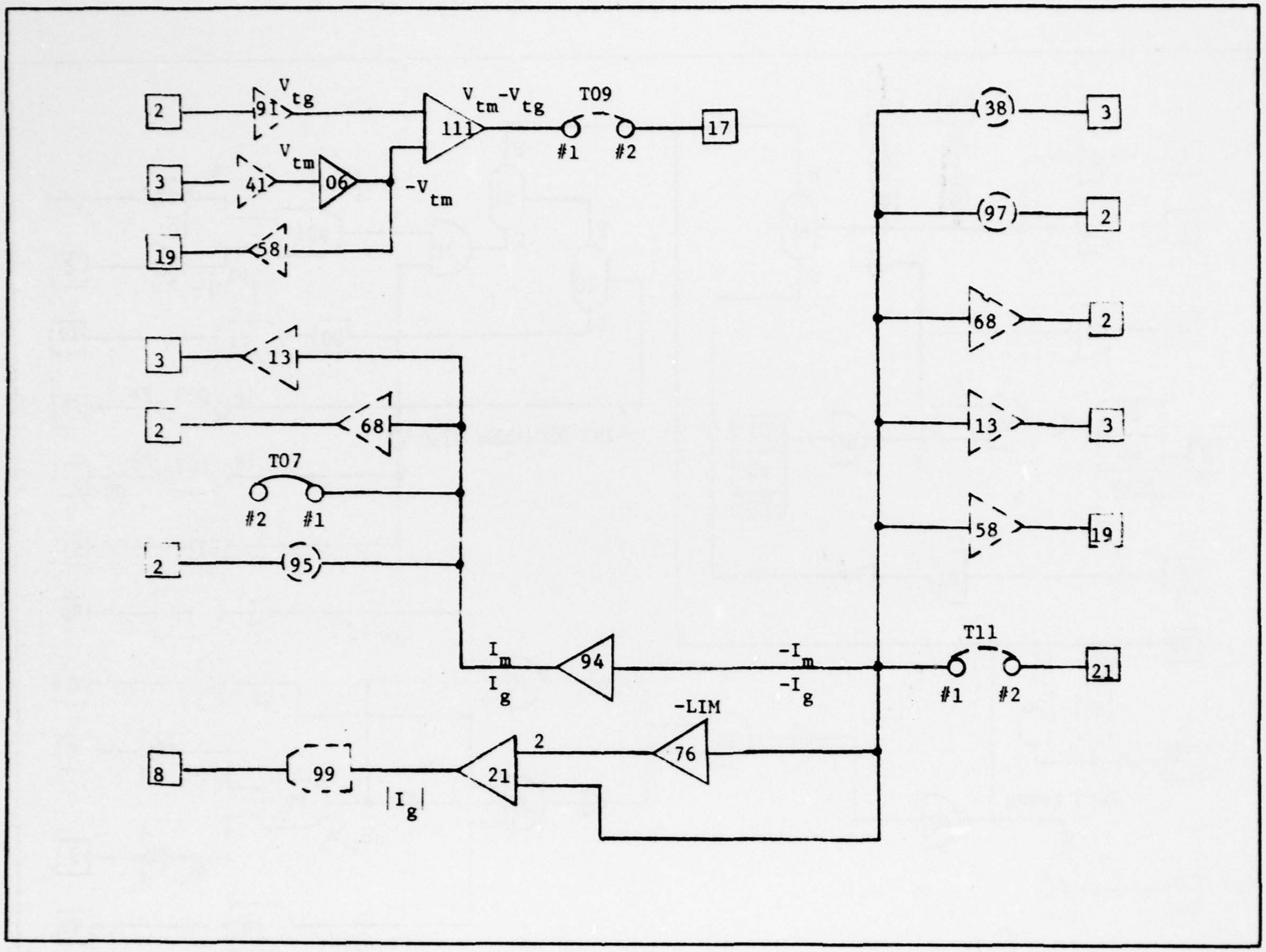
The dynamic braking network (an option for controlling regeneration) requires the difference between the motor and generator terminal voltage as its input and produces as output the armature current. This block shows the input-output signals and the trunks which transfer the dynamic braking signals between consoles 1 and 2.

Block 8, Regeneration Control (8a, 8b)

This block contains the logic which controls the regeneration cycle. Details of the actual operation can be found in Section X, Regeneration Control by Dynamic Braking of the Motor and Section XI, Regeneration Control by Acceleration of the Turbine-Generator Rotating Inertias.

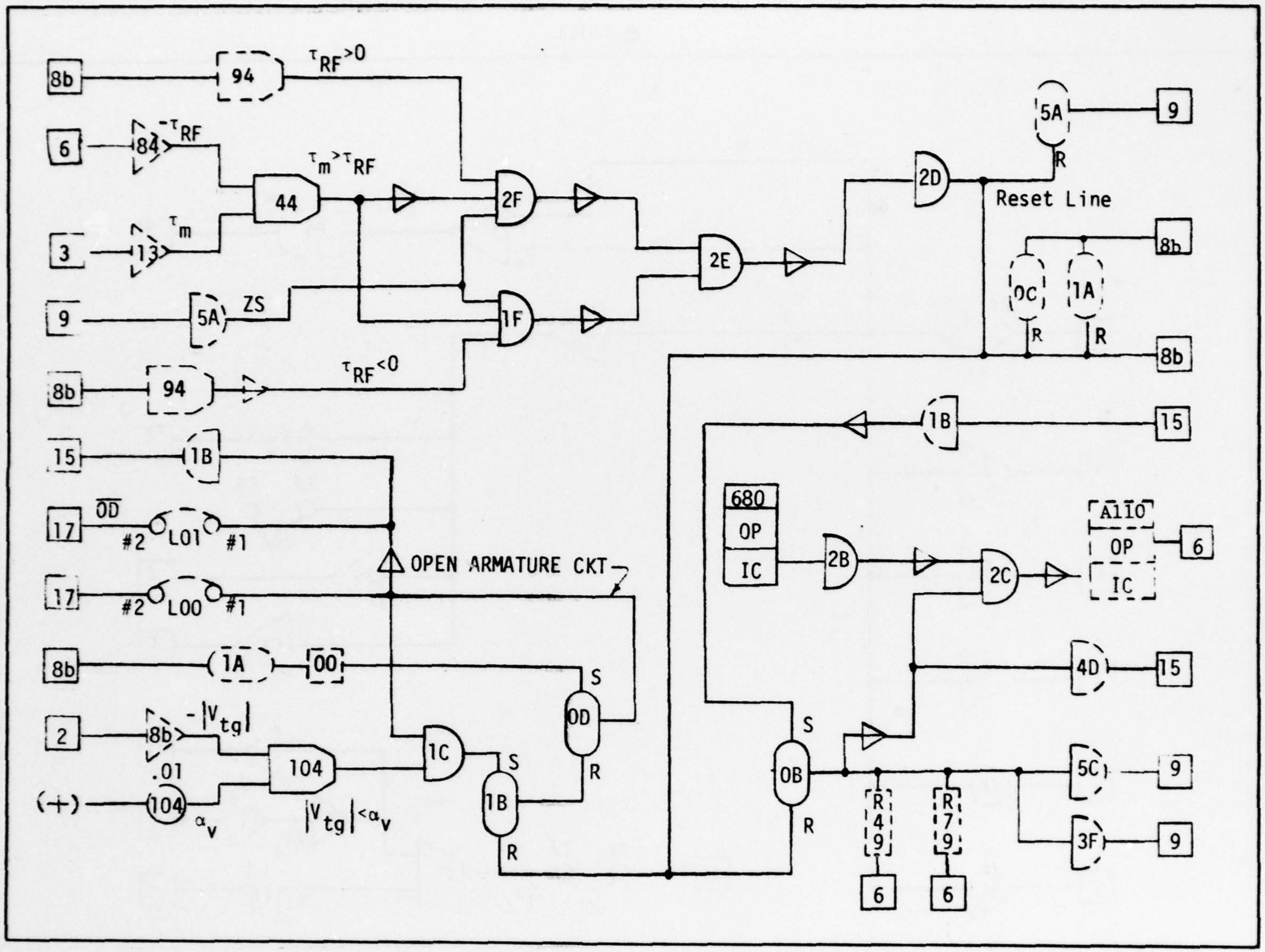
Block 9, Generator Friction Brake Control

This block in conjunction with Block 15 controls the generator friction brake during the regeneration cycle. An operational description is found in Section XI, Regeneration Control by Acceleration of the Turbine-Generator Rotating Inertias.

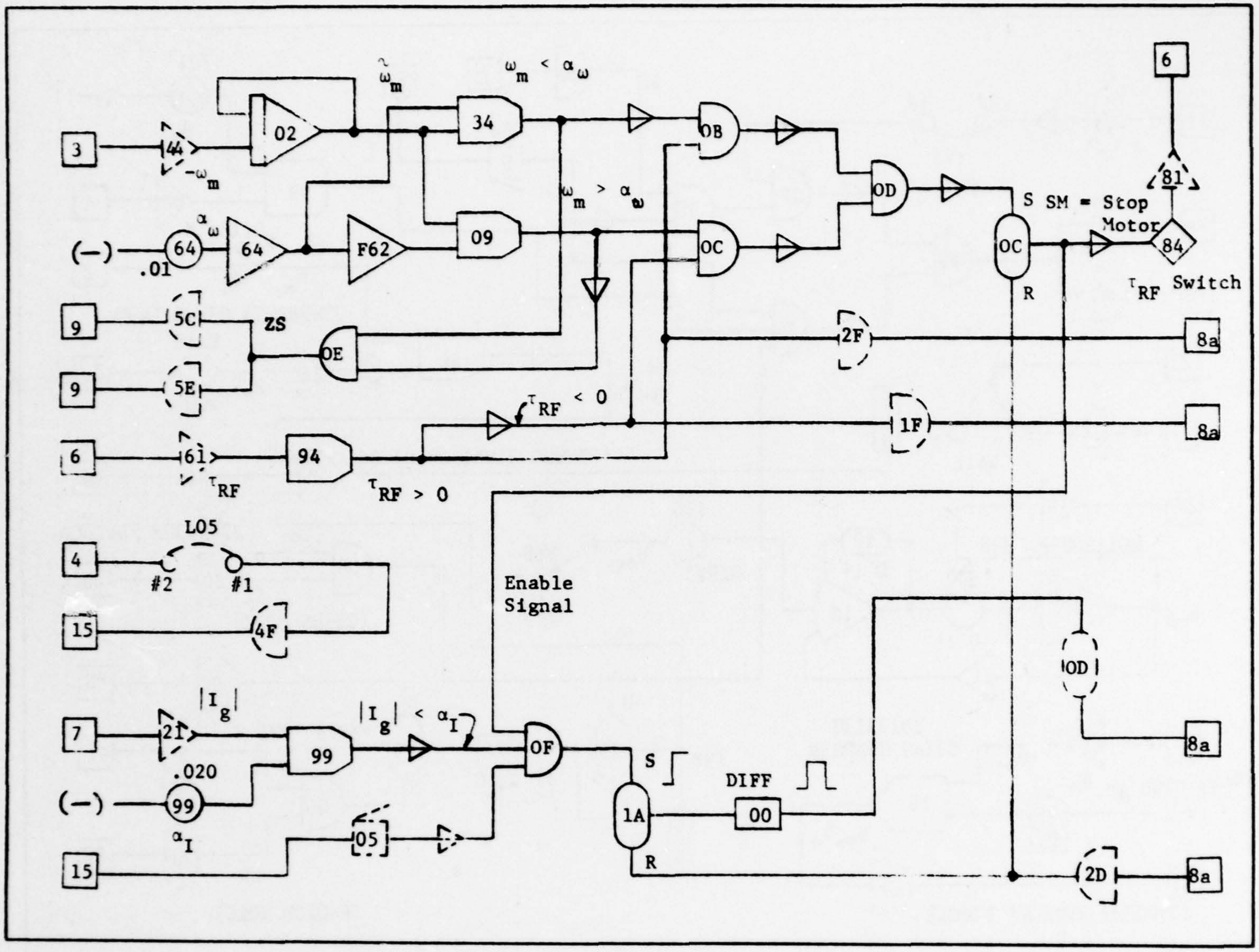


BLOCK 7

Interface to Dynamic Braking Coupling Network

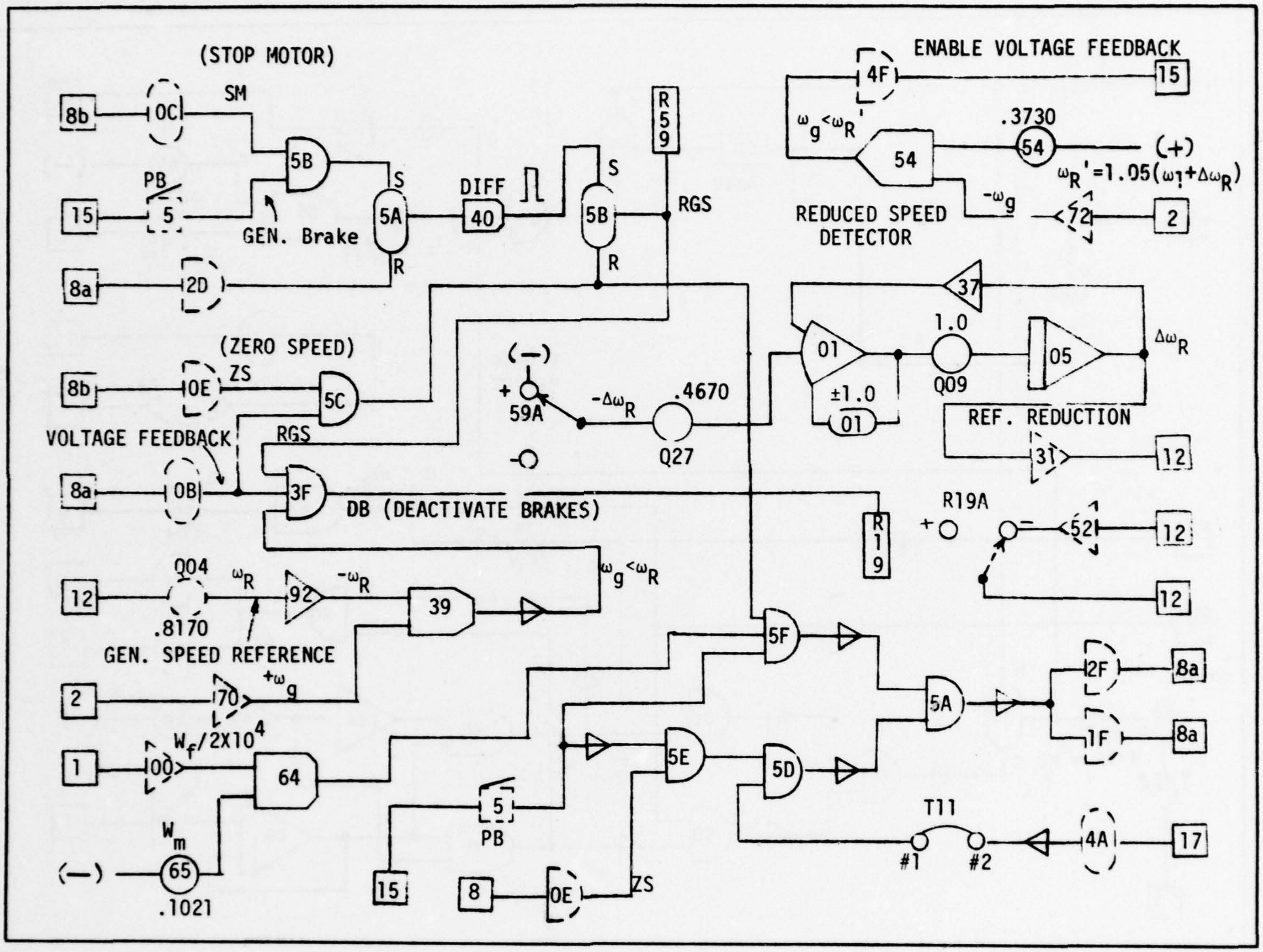


Block 8a Regeneration Control



BLOCK 8b

Regeneration Control



Block 9 Generator Friction Brake Control, Part I

Block 10, Friction Brake Servo Valve

The simulated friction brake is driven by a three way servo valve which is used to regulate the pressure of the actuator. The motion of the valve spool is X_V which is to follow a reference position, X_R. The second order dynamics associated with the valve spool are simulated by integrators A00 [10], A70 [10] and amplifier A69 [10]. Pot P40 [10] sets the undamped natural frequency and Pot P42 [10] determines the relative damping.

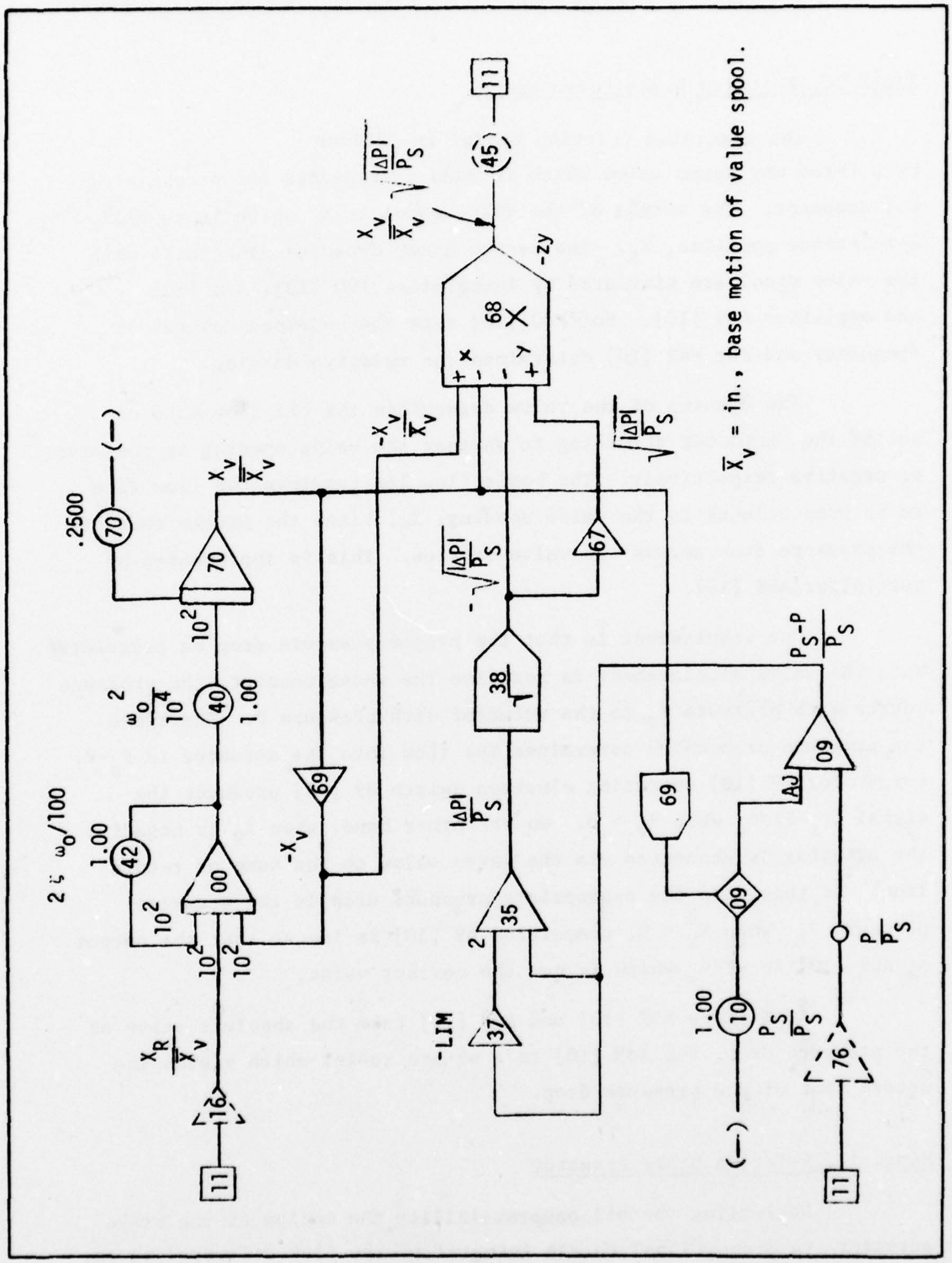
The opening of the valve determines the oil flow into or out of the actuator according to whether the valve opening is positive or negative respectively. The basic flow law requires the flow rate to be proportional to the valve opening, X_V, times the square root of the pressure drop across the valve orifice. This is implemented by multiplier A68 [10].

One requirement is that the proper pressure drop be calculated. When the valve displacement is positive the valve connects the pressure source with pressure P_s to the actuator with pressure P. Therefore the pressure drop which determines the flow into the actuator is P_s-P. Comparator 69 [10] operating electron switch 09 [10] produces the signal $(P_s-P)/P_s$ when $X_V > 0$. On the other hand, when X_V is negative the actuator is connected via the servo valve to the sump or return line. In this case the appropriate pressure drop is the actuator pressure P. When $X_V < 0$, comparator 69 [10] is low so that the output of A09 [10] is $-P/P_s$ which is now the correct value.

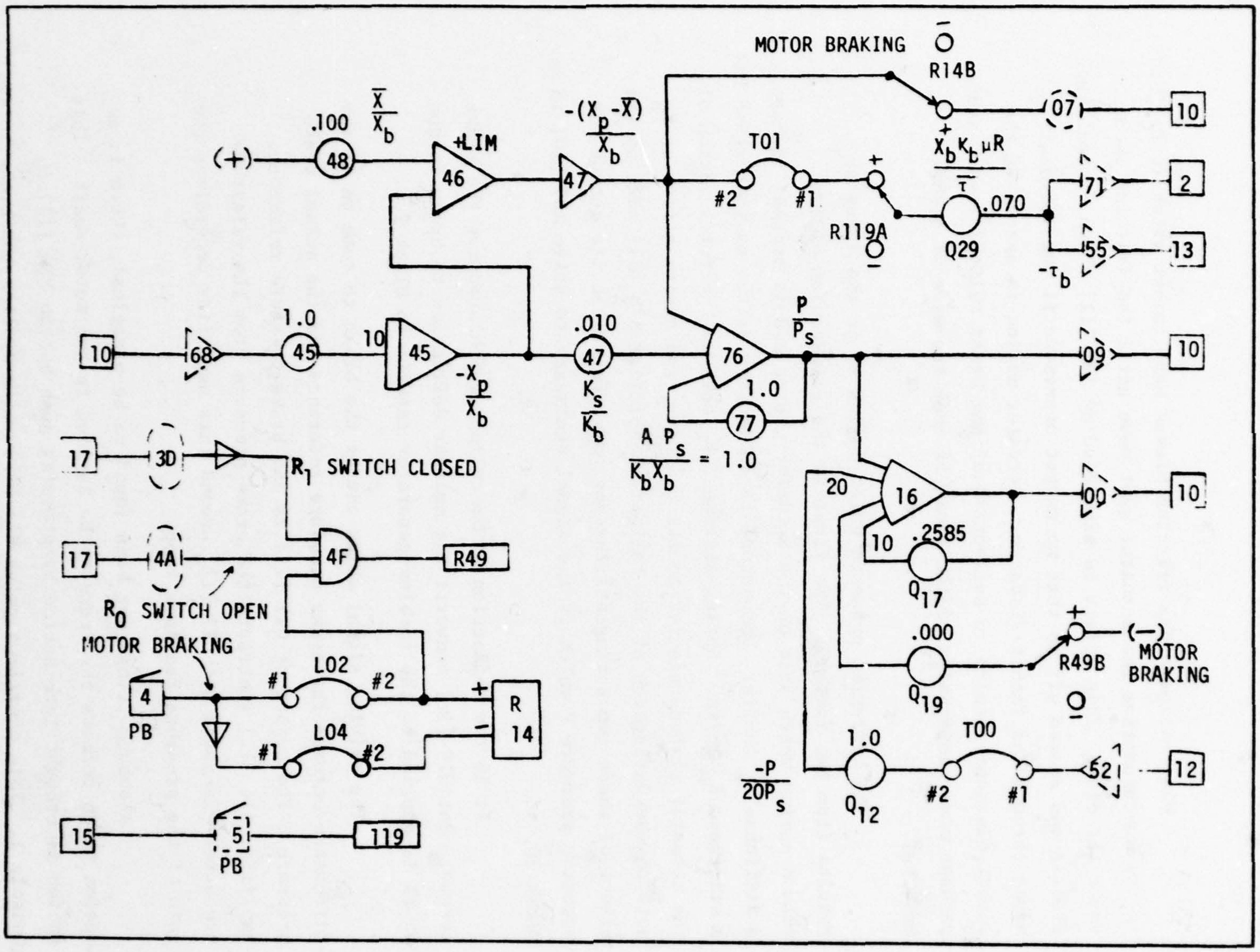
Amplifiers A37 [10] and A35 [10] take the absolute value of the pressure drop, and A38 [10] is a square rooter which yields the square root of the pressure drop.

Block 11, Friction Brake Actuator

Neglecting the oil compressibility, the motion of the brake actuator is proportional to the integral of the flow delivered by the servo valve. Integrator A45 [11] performs this integration.



Block 10 Friction-Brake Servo Value (console 2)



Block 11 Friction Brake Actuator (Console 2)

Most caliper-type friction brakes have inshot which is defined as the distance that the actuator must move until the friction shoes touch the disk. This effect is simulated by A46 [11] which is positive limited and biased off so that no output occurs until the actuator moves through the inshot distance. Actuator motion in excess of the inshot distance results in deflection of the brake caliper itself and perhaps some compression of the shoes if they are made of a soft material.

The hydraulic pressure which builds up in the actuator results from two factors. The first is the compression of the return spring which acts on the actuator piston and is assumed to have a stiffness K_s lbs/in. The second is deflection of the caliper which has a stiffness K_b lb/in. Spring stiffness K_s acts on the total motion of the actuator piston relative to its cylinder, and spring stiffness K_b acts on the deflection of the caliper. Amplifier A76 [11] adds up the effect of these two spring stiffnesses and produces at its output the actuator pressure P which is the signal necessary to drive A09 [10] in Block 10.

It is the deflection of the caliper which produces the brake torque. Pot Q29 [11] converts the caliper deflection to brake torque which is applied to the turbine-generator inertia in Block 2.

The driving signal which causes the brake to come on is the difference between the brake pressure reference and the actual brake pressure. The output of Q12 [11] is the brake pressure reference. Amplifier A16 [11] subtracts the brake pressure from the reference pressure. Feedback pot Q17 [11] around this amplifier determines the gain of the pressure feedback loop.

Although it has not been found to be practical, there is an option which permits the brake to be applied to the motor shaft. This option is brought into action by pressing push button PB4 [11] on Console 1. This energizes relay R14 [11] which applies the brake torque to the motor shaft via the circuitry in Block 18. Motor braking is allowed only in conjunction with dynamic braking and is permitted only after the

final dynamic braking resistor is inserted and discontinued when the shorting switch closes. Logic AND gate 4F [11] and relay R49 [11] implement this control.

Block 12, Turbine Speed Control

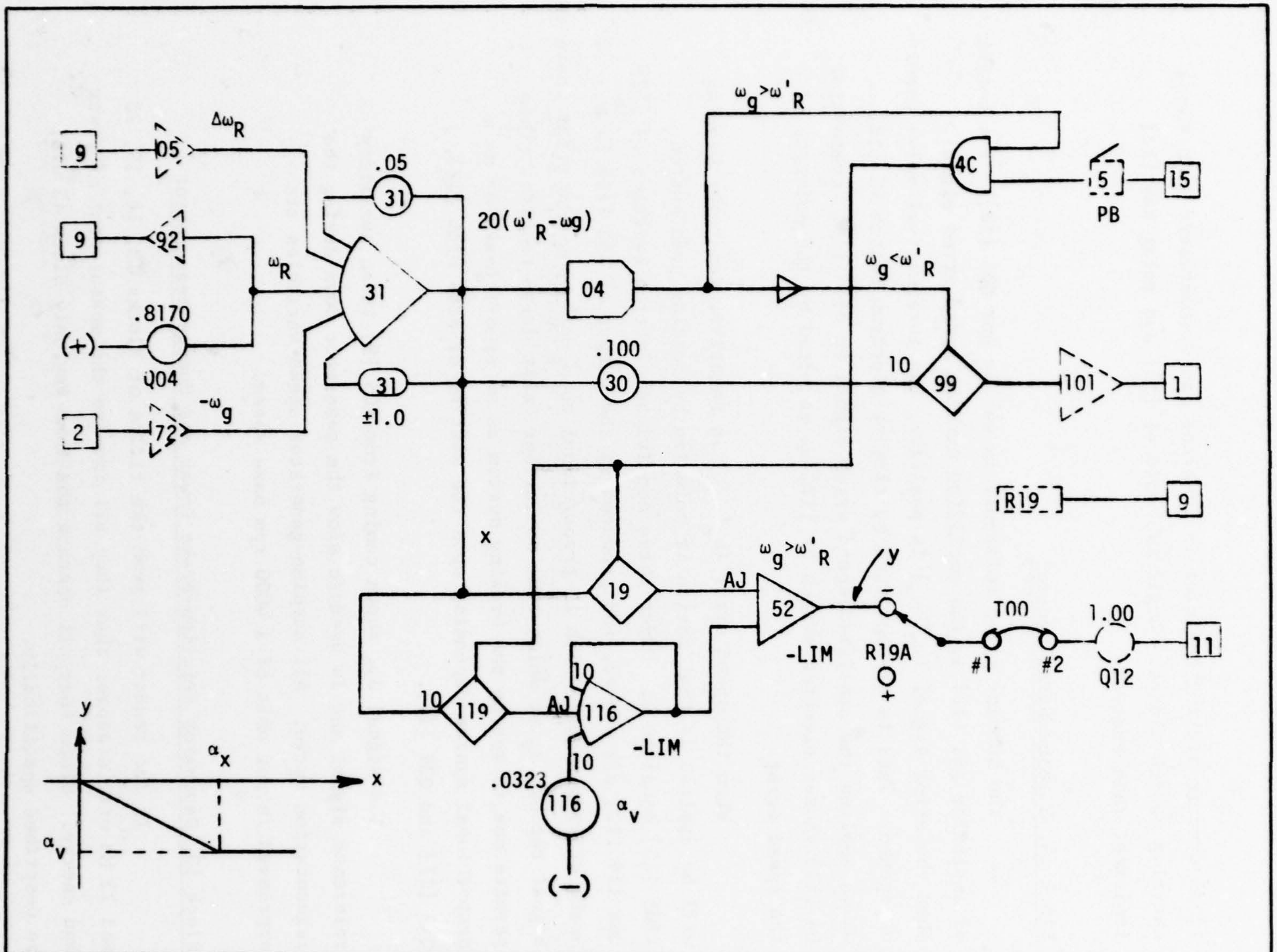
The turbine speed reference is set by pot Q04 [12]. The output of amplifier A31 [12] is the amplified turbine speed error signal. When the error signal ($\omega_R{}'-\omega_g$) is positive, the turbine fuel valve should be opened. This is accomplished by closing electron switch 99 [12] which applies the amplified speed error signal to A101 [1]. Comparator 04 [12] closes electron switch 99 [12] as required by the polarity of the speed error.

When the speed error ($\omega_R{}'-\omega_g$) is negative, generator braking will be applied if that option is selected by setting push button PB05 [15] equal to 1. Under these conditions electron switches 19 [12] and 119 [12] are closed, and produced at the output of A52 [12] is a brake driving signal which is proportional to $\omega_g-\omega_R{}'$ up to the point where this signal reaches α_V at which time no further brake drive results. This permits one to set up the braking system as an on-off brake or as a proportional system depending upon the setting of pots P116 [12], Q12 [11] and Q29 [11].

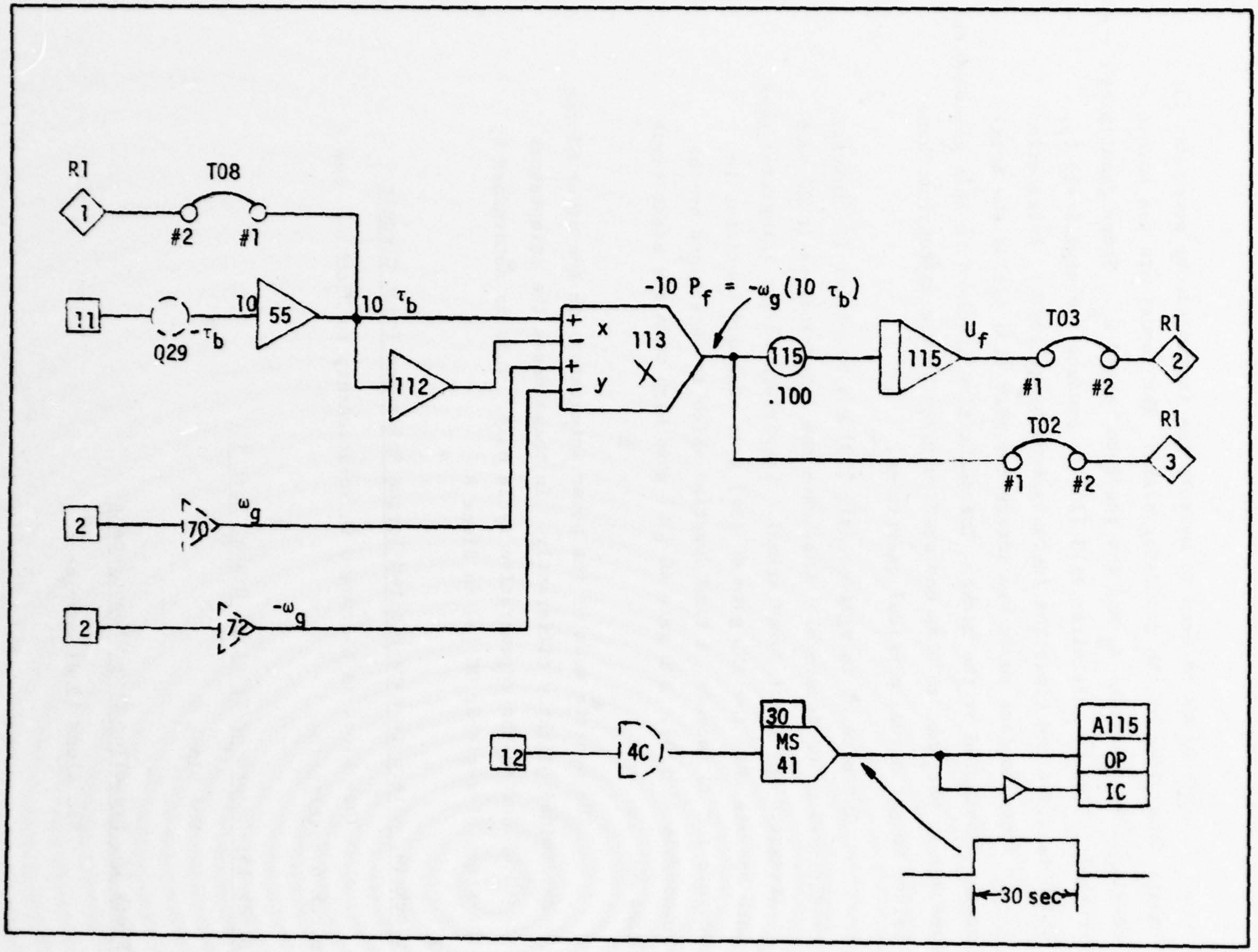
The signal $\Delta\omega_R$ shown coming from A05 [9] is an auxiliary reference signal and is used to slow the generator down during the regeneration cycle. All turbine-generator speed variables are expressed in per unit of a 4000 rpm base speed.

Block 13, Generator Friction-Brake Power and Energy Measurement

If the reader will scan the titles of Blocks 13, 16, 19, 20 and 23 he will discover that they all involve the measurement of power and energy. Since they all operate the same way,only Block 13 will be described specifically.



Block 12 Turbine Speed Control



Block 13 Generator Friction Brake Power and Energy Measurement

70

This block is used to measure the instantaneous power and the energy dissipated by the generator brake. The inputs are the torque developed by the brake τ_b and the generator speed ω_g. These quantities are multiplied by multiplier A113 [13] to produce the signal -10 P_f, which is minus ten times the instantaneous brake power. Integration of the instantaneous power via integrator A115 [13] yields the total energy dissipated by the brake. The quantities involved in this calculation are all in per unit so that one must multiply by the appropriate base values to get actual physical quantities.

The mode of integrator A115 [13] may be either IC (initial conditions) or OP (operate). Only when the integrator is in OP does it integrate the input power signal. From Block 13 the integrator goes into operate when the AND gate 4C [12] goes high and continues in operate for 30 seconds, a time duration which is determined by the monostable 41 [13]. AND gate 4C [12] goes high when the brake first goes on.

The operate mode of the power integrators in the other blocks is determined slightly differently. In these cases the integrators are in OP during the regenerative cycle only. This is determined by the state of register OC [8] in Block 8.

Block 14, Alternate Rate-Limited Torque Reference Input Circuit

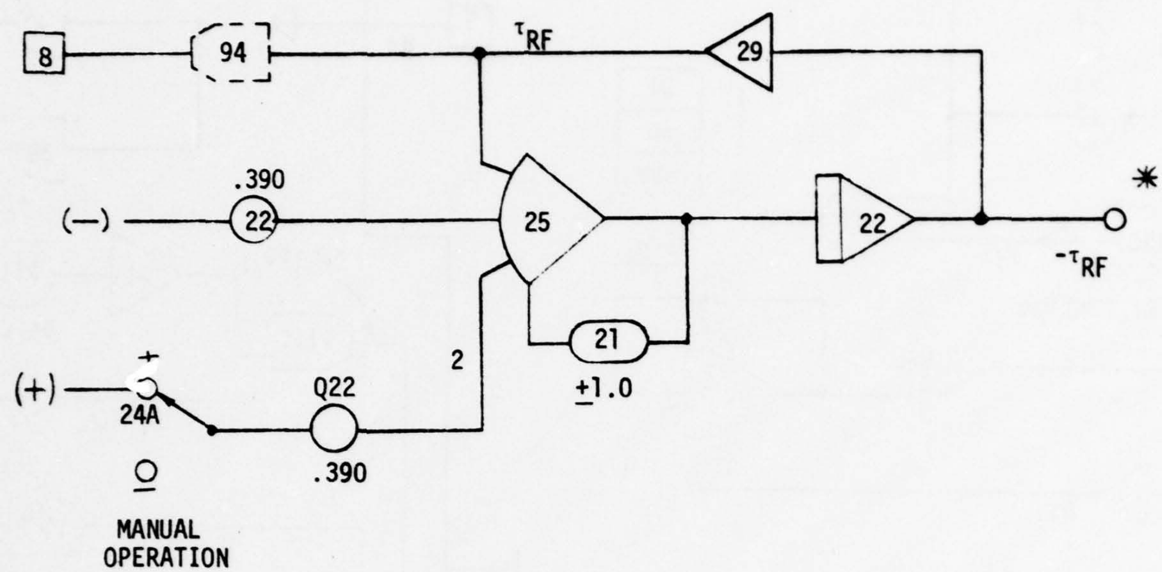
This block is discussed in relationship to Block 6. See Block 6 description.

Block 15, Generator Friction Brake, Part II

See Block 9.

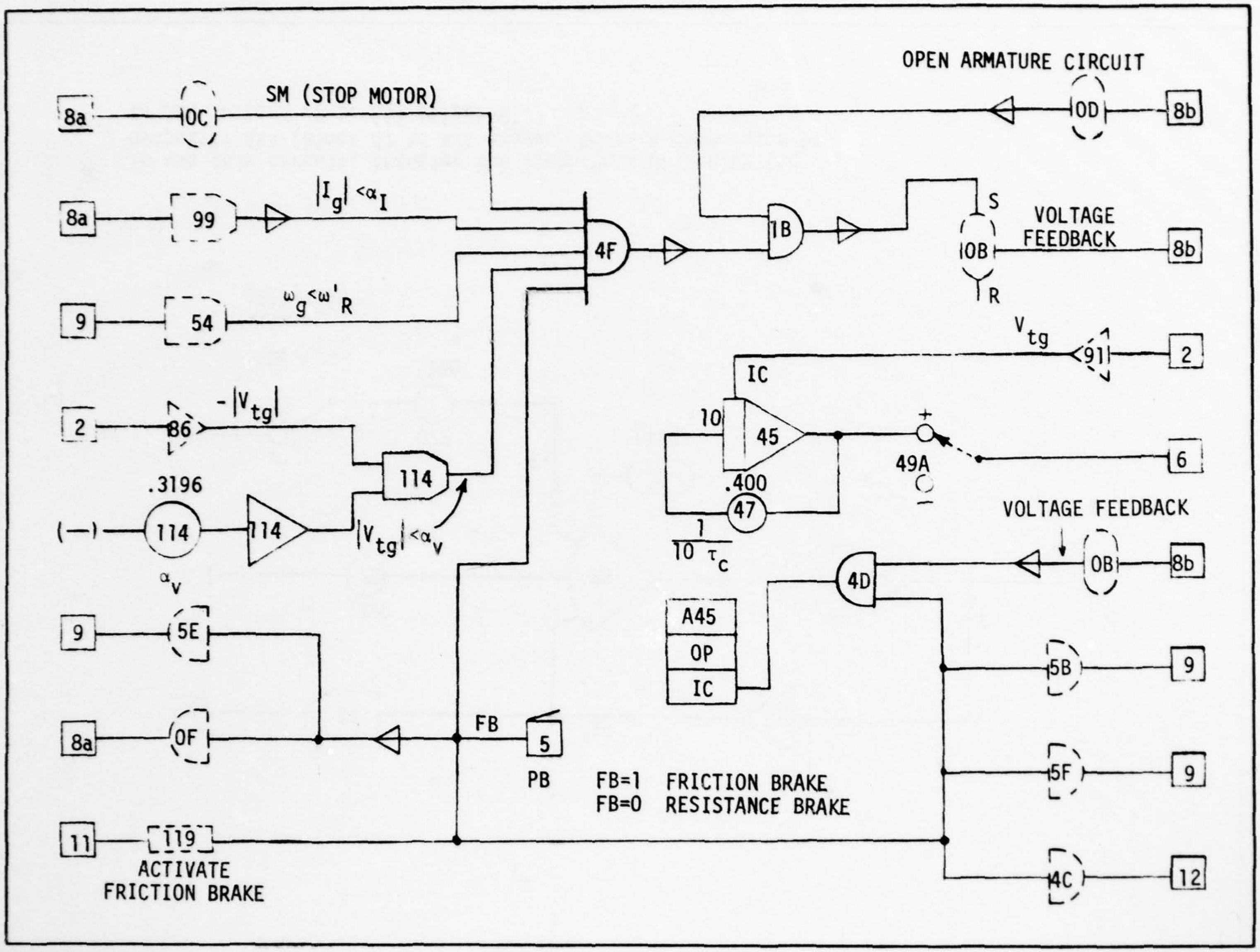
Block 16, Propeller Power Measurement

See Block 13 discussion.

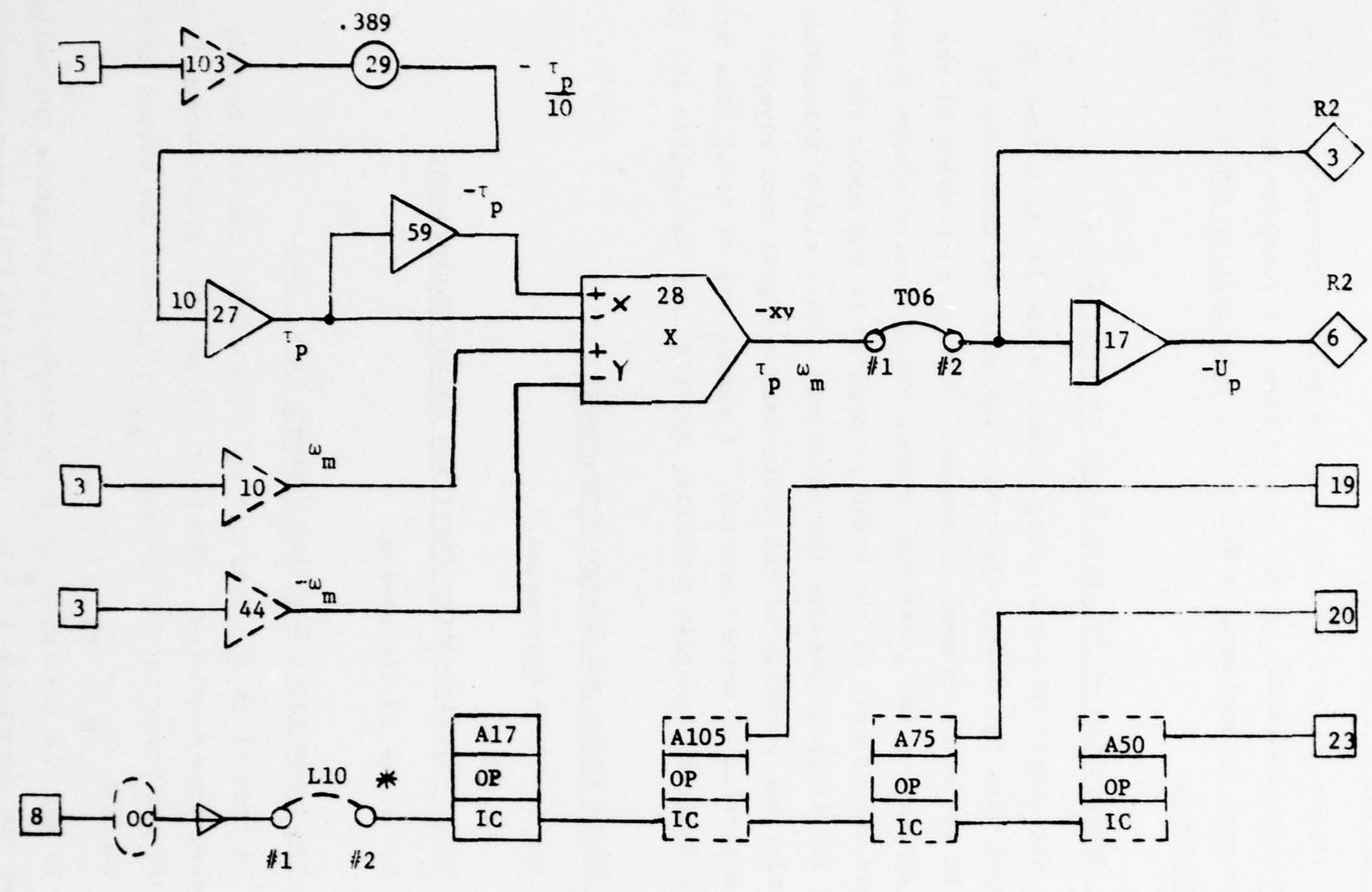


* To use this circuit, transfer the components driven by the output of A84 (Block 6) to A22 above. Connect comparator 94 to A29 instead of to A61 (Block 6).

Block 14 Alternate Rate - Limited Torque Reference Input Circuit



Block 15 Generator Friction Brake Control, Part II



* Integrators are in operate in the SM (stop motor) condition only.

BLOCK 16

Propeller Power Measurement

Block 17, Armature Relay Controls

This block provides the logic signals required to close in the dynamic braking resistors at the proper time. A complete description of this process is included in Section X, Regeneration Control by Dynamic Braking of Motor.

Block 18, Application of Friction Brake to Motor Shaft

The output of our braking system, Block 11, is a braking torque which does not change algebraic sign when the direction of rotation of the shaft changes direction. This is no problem if the brake is applied to the generator because the generator always rotates in the same direction. If the brake is applied to the motor the situation is different because the motor may rotate either direction. Consequently, the polarity of the brake-torque signal must reverse with the direction of motor rotation. A simple way of doing this makes use of the limited high-gain amplifier A61 [18] and multiplier A63 [18].

Block 19, Motor Power and Energy Measurement

See Block 13 discussion.

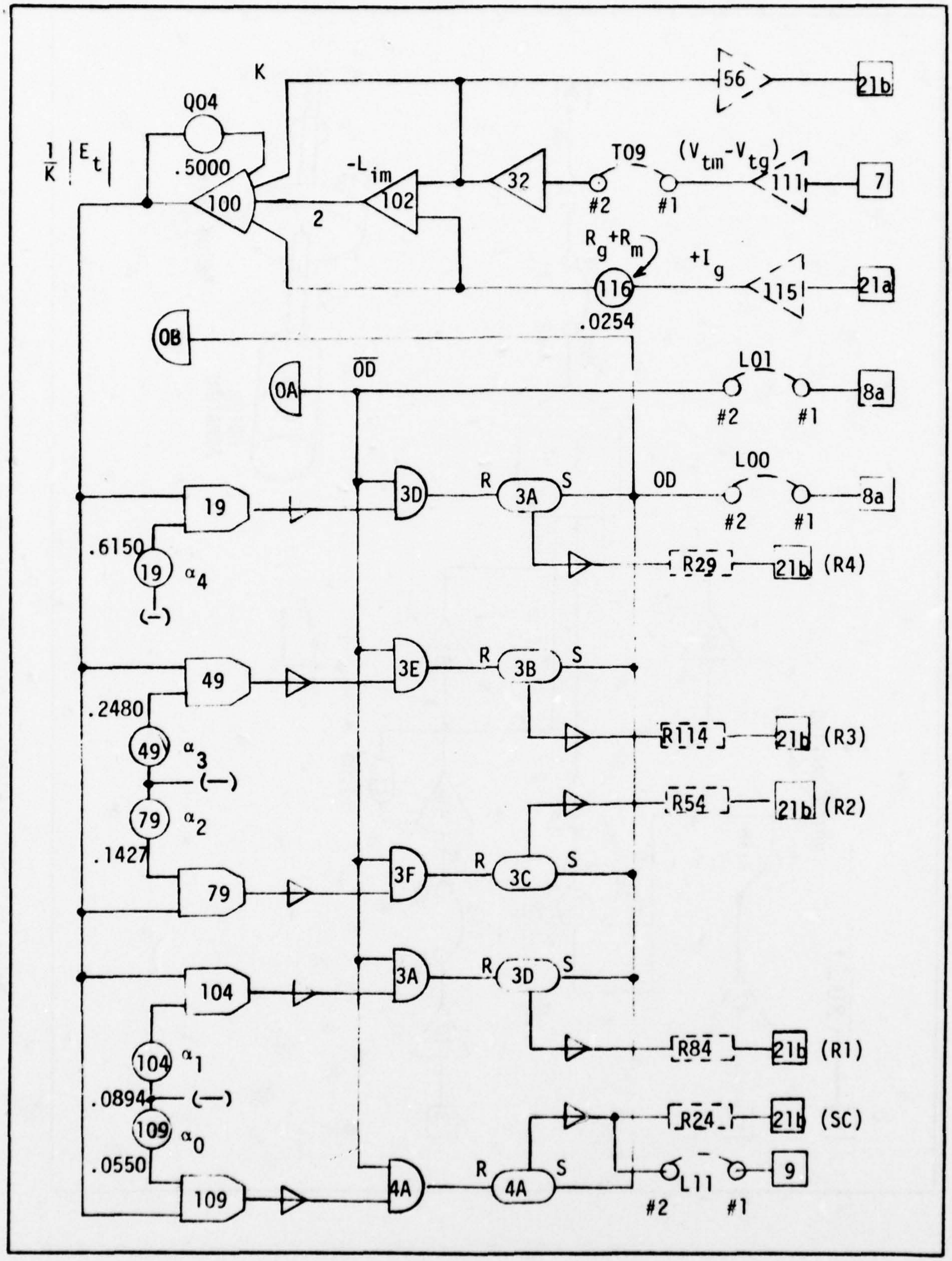
Block 20, Motor Friction-Brake Power and Energy Measurement

See Block 13 discussion.

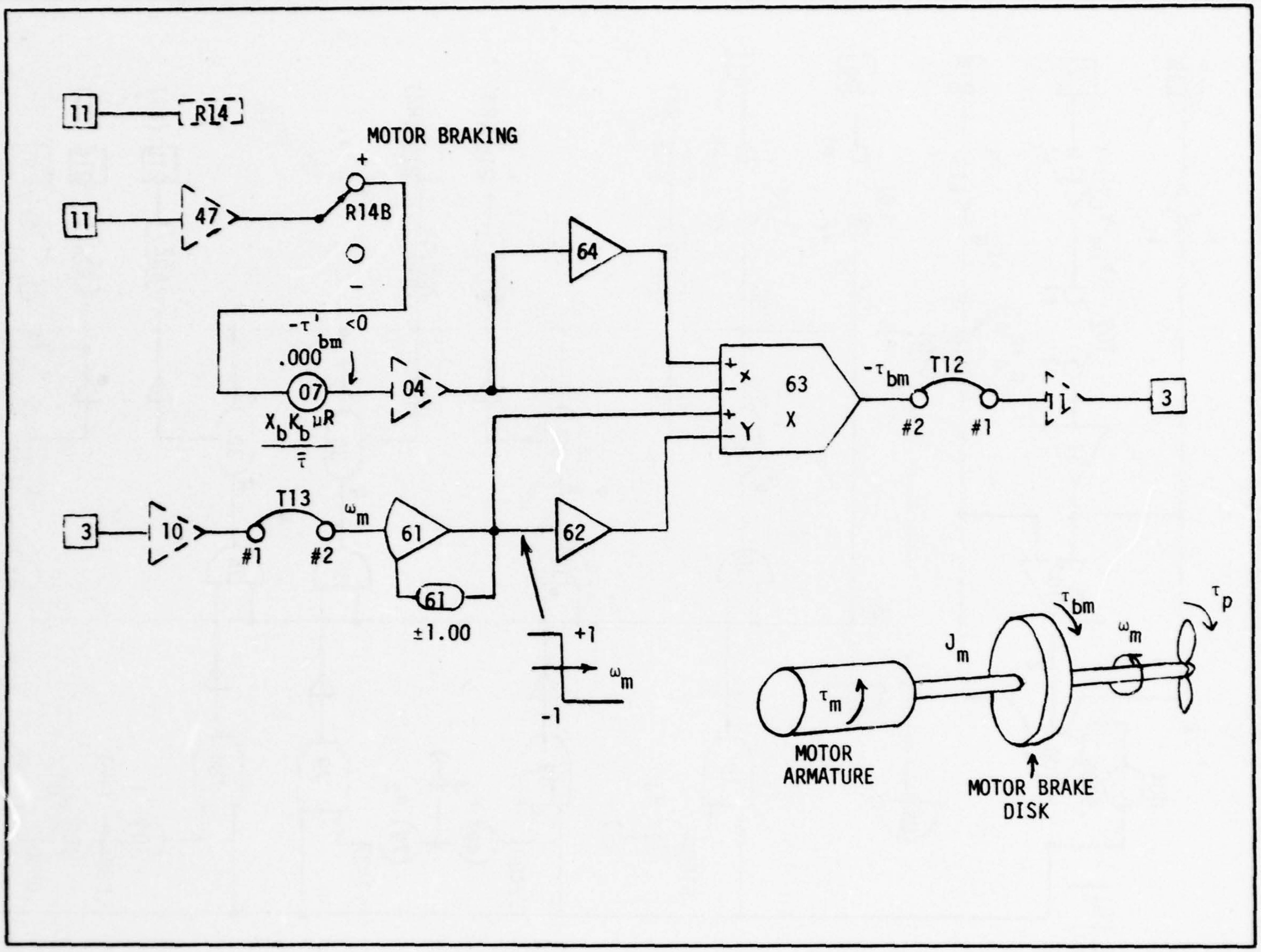
Block 21, Motor-Generator Coupling Network (21a, 21b)

In this block the armature self inductance and the dynamic braking network are simulated. Figure 9.7 shows the circuit which is simulated. The input to the block is the voltage ($V_{tg} - V_{tm}$) and the output is the generator current, I_g or I_m.

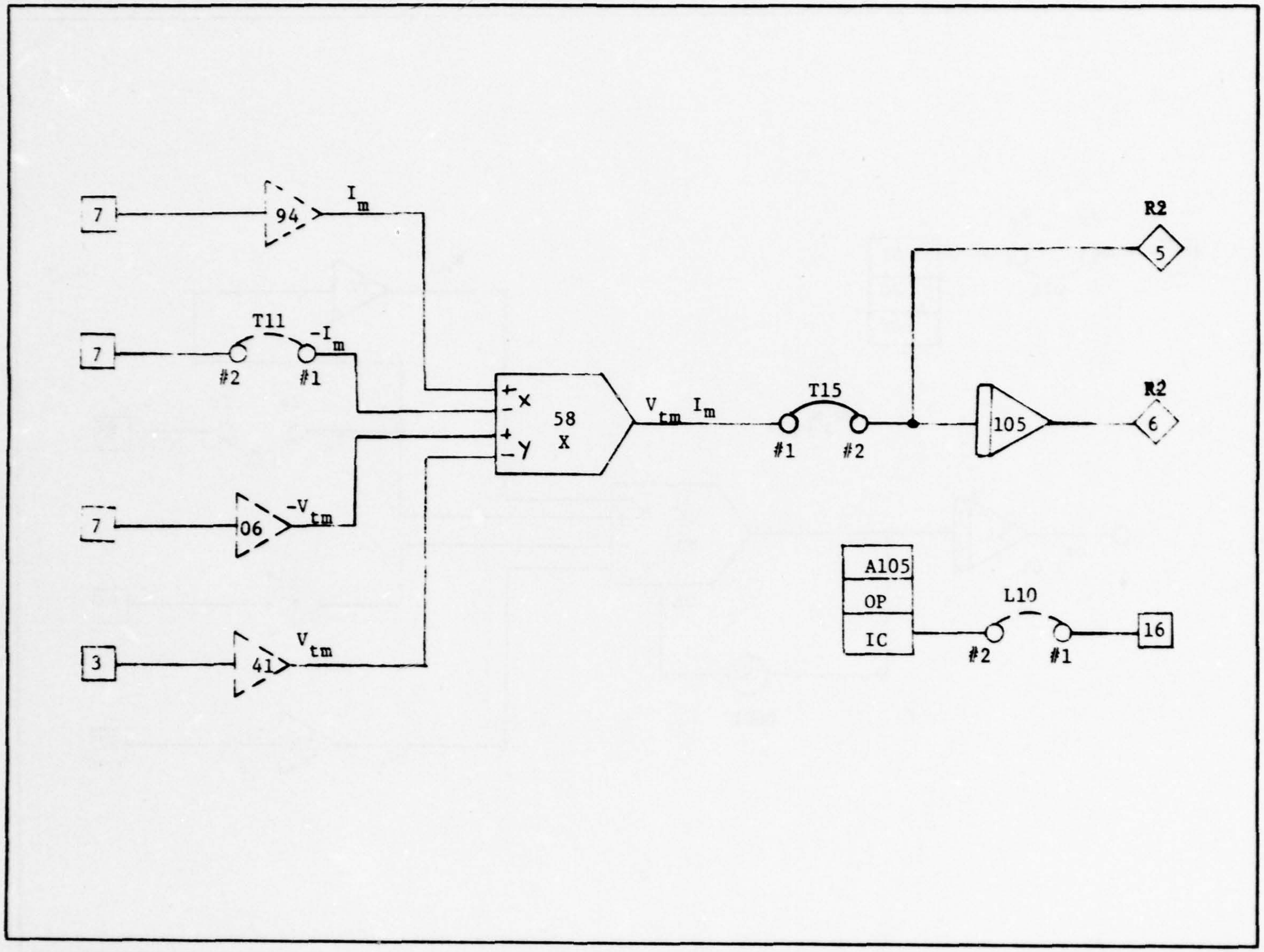
To get the current I_g it is necessary to integrate the voltage drop across the inductance $L_m + L_g$. Amplifier A56 [21] generates the inductance voltage and integrator A115 [21] integrates the voltage to



Block 17 Armature Relay Controls (See Block 21)

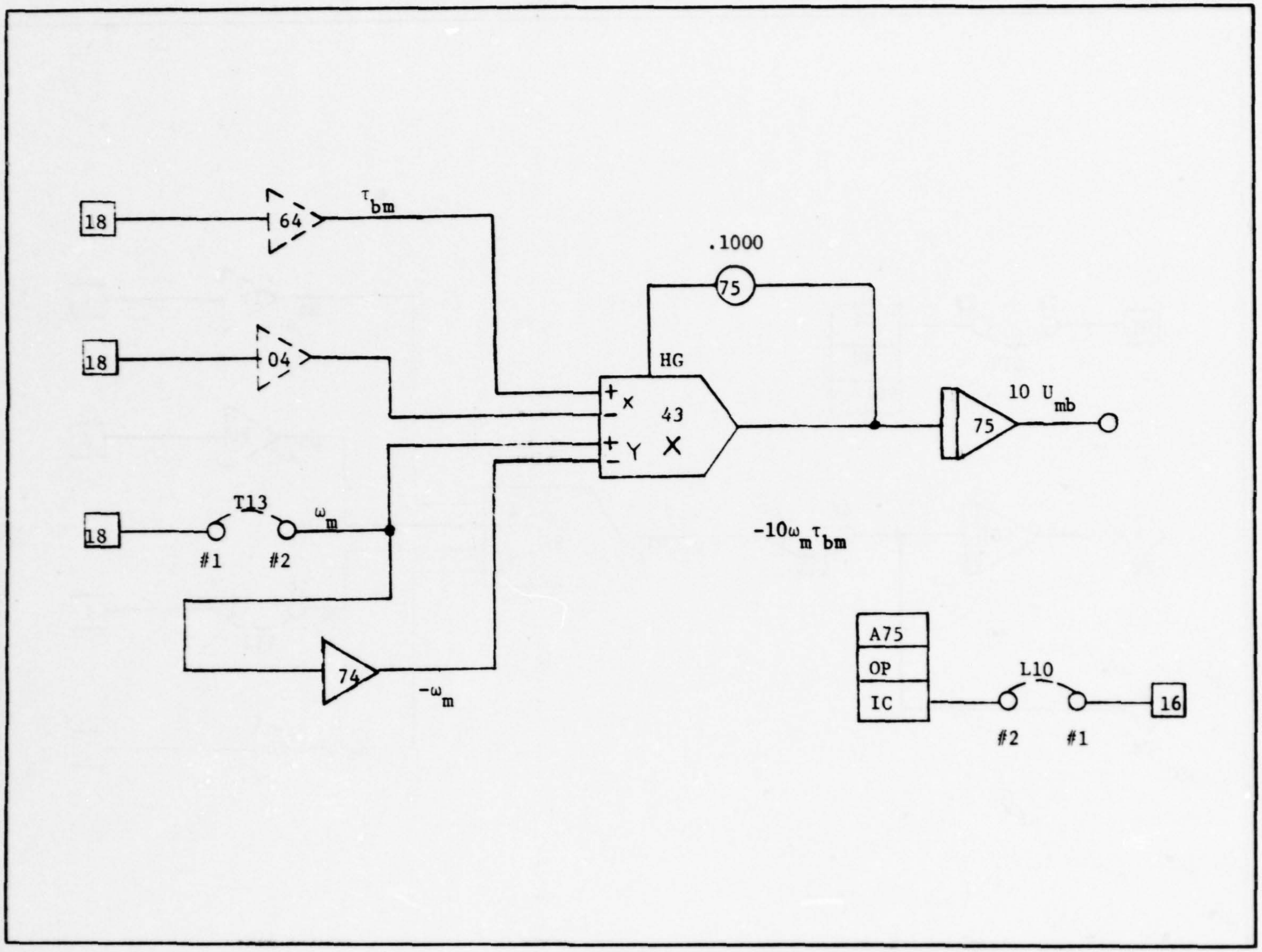


Block 18 Application of Friction Brake to Motor Shaft (Console 2)



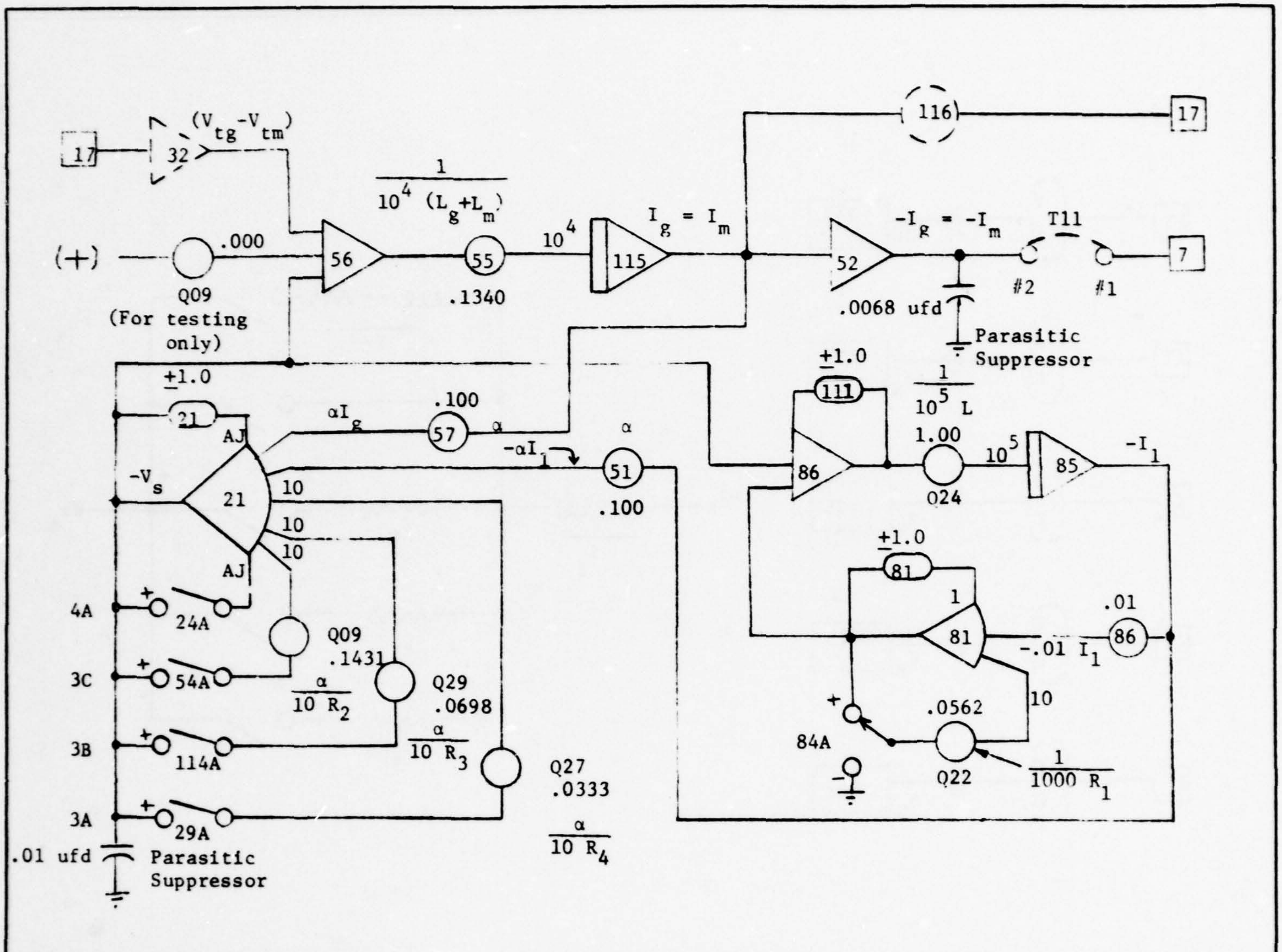
BLOCK 19

Motor Power and Energy Measurement



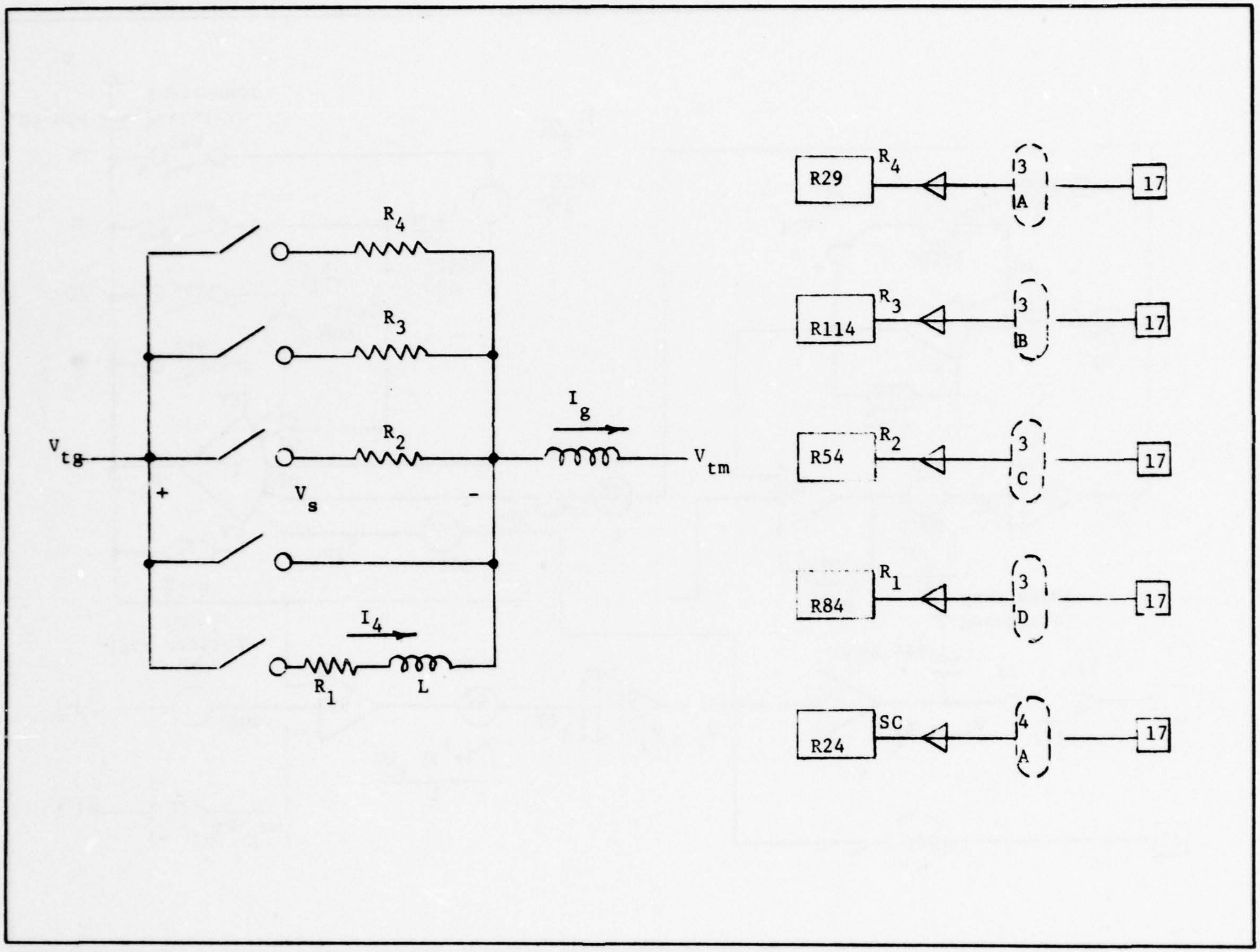
BLOCK 20

Motor-Friction-Brake Power and Energy Measurement



BLOCK 21a

Motor-Generator Coupling Network



BLOCK 21b

Motor-Generator Coupling Network

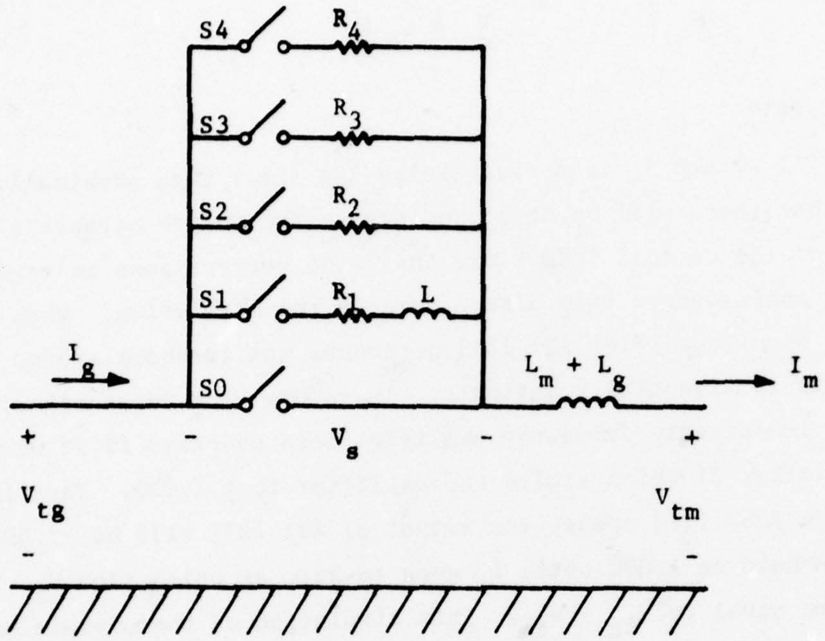


Figure 9.7. Dynamic Braking Coupling Network.

yield the armature current, I_g. The voltage difference $V_{tg} - V_{tm}$ is an output from Block 17, A32 [17]. The voltage V_s across the dynamic braking resistor network is determined by the switch closures and the instantaneous value of I_g.

Amplifier A21 [21] calculates the value of V_s. To see how this works, consider the closure of switch S_4 only. This is closed in the analog simulation by closing relay 29A [21] (all other feedback paths around A21 [21] are dead). Amplifier A21 [21] is a high-gain amplifier so that the sum of its inputs must be zero. Therefore

$$\alpha I_g + (-V_s)\left(\frac{\alpha}{R_4}\right) = 0 \tag{9.14}$$

This leads to the fact that

$$V_s = I_g R_4 \tag{9.15}$$

which is correct.

If switch S_4 is opened (Relay 29A [21]), then physically we know that there will be an arcing across the switch because of the presence of the circuit inductance until the current goes to zero. Something analogous to this also occurs in the simulation. When relay R29A [21] opens, amplifier A21 [21] no longer has feedback around it so its gain is essentially infinite. Therefore the input signal αI_g would immediately drive the amplifier into overload if it were not for the limiter 21 which limits the amplifier to $\pm$ 1.000. Thus if $I_g > 0$ when R29A [21] opens, the output of A21 [21] will be -1.000 and V_s will be held at 1.000 until I_g goes to zero at which time V_s will become equal to $V_{tg} - V_{tm}$. This simulation of the circuit holds the arc voltage at $\pm$ 1.000 until the current goes to zero.

If all three switches S_4, S_3 and S_2 are closed, the algebraic condition which must be satisfied is

$$\alpha I_g - V_s \left(\frac{\alpha}{R_4} + \frac{\alpha}{R_3} + \frac{\alpha}{R_2} \right) = 0 \tag{9.16}$$

or

$$V_s = I_g / \left(\frac{1}{R_4} + \frac{1}{R_3} + \frac{1}{R_2} \right) \tag{9.17}$$

This we recognize as the proper condition.

Closure of Switch S_o forces V_s to be zero, which is accomplished in the simulation by closing relay R24A [21]. This connects the amplifier output directly to the summing junction resulting in zero gain of the amplifier.

Closure of switch S_1 requires special consideration because its resistor is connected in series with inductance L. Closure of this switch is simulated by closing relay R84A [21] as shown.

The output of amplifier A86 [21] is $V_s - I_1R_1$ which equals the voltage drop across the inductance L. Integrator A85 [21] integrates this voltage and produces as its output the current $-I_1$. When relay R84A [21] is low (which corresponds to S_o being open), there is no feedback around A8 [21] so that I_1 will be zero, and the output of A81 [21] will just cancel out the signal $-V_s$ which drives A86 [21]. The limiter around A81 [21] prevents an overload if relay 84A [21] should go low while I_1 is not zero. This action simulates the arcing across the switch S1 if it opens when the current through R_1 is not zero.

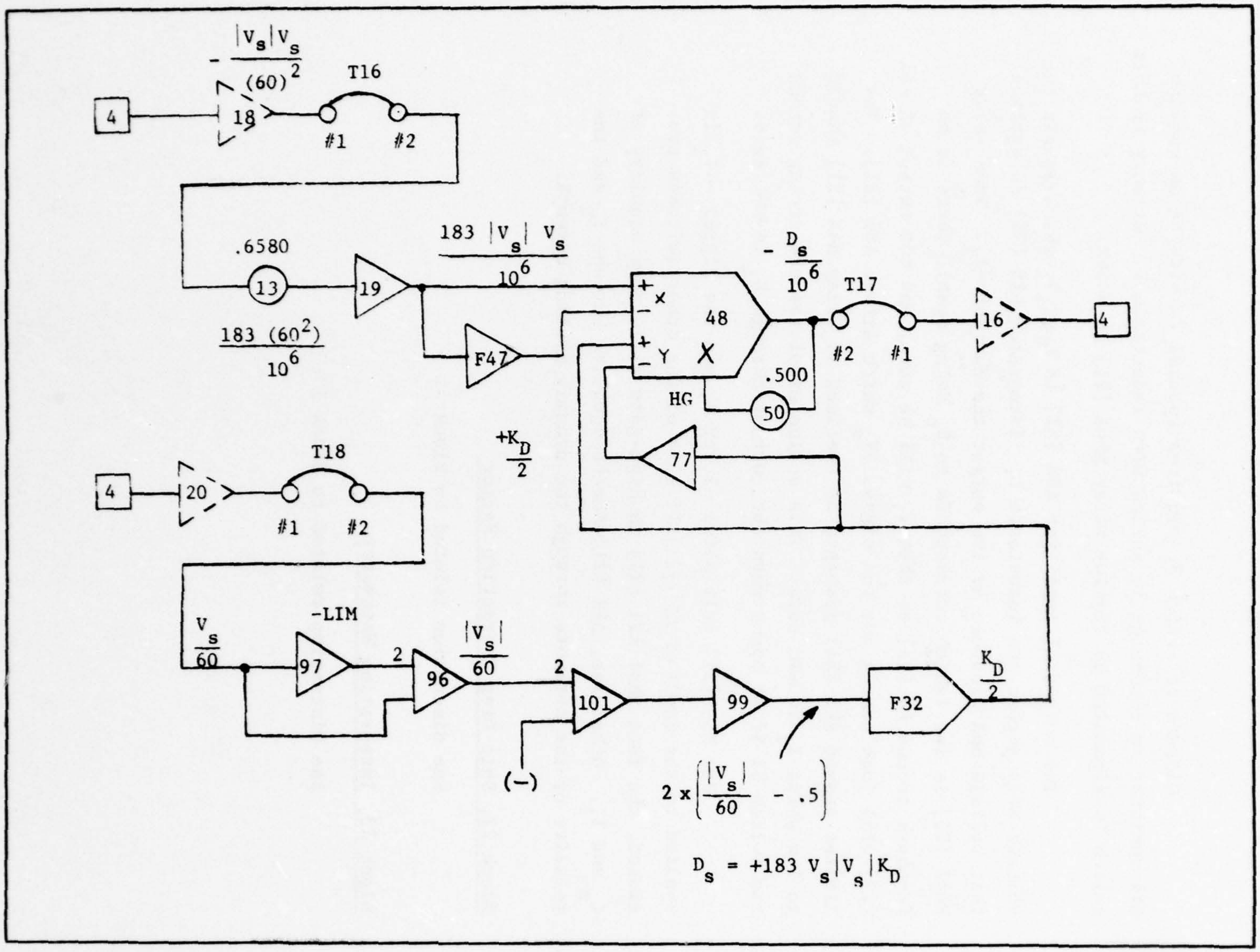
Pot P51 [21] multiplies $-I_1$ by α, and the signal $-\alpha I_1$ is applied to the input of A21 [21]. If none of the other switches are closed, the fact that A21 [21] is high-gain will force equality of I_g and I_1. Otherwise, A21 [21] forces equality between I_g and the totality of the currents through the dynamic braking network.

Block 22, Ship Drag Correction Factor

See discussion related to Block 4.

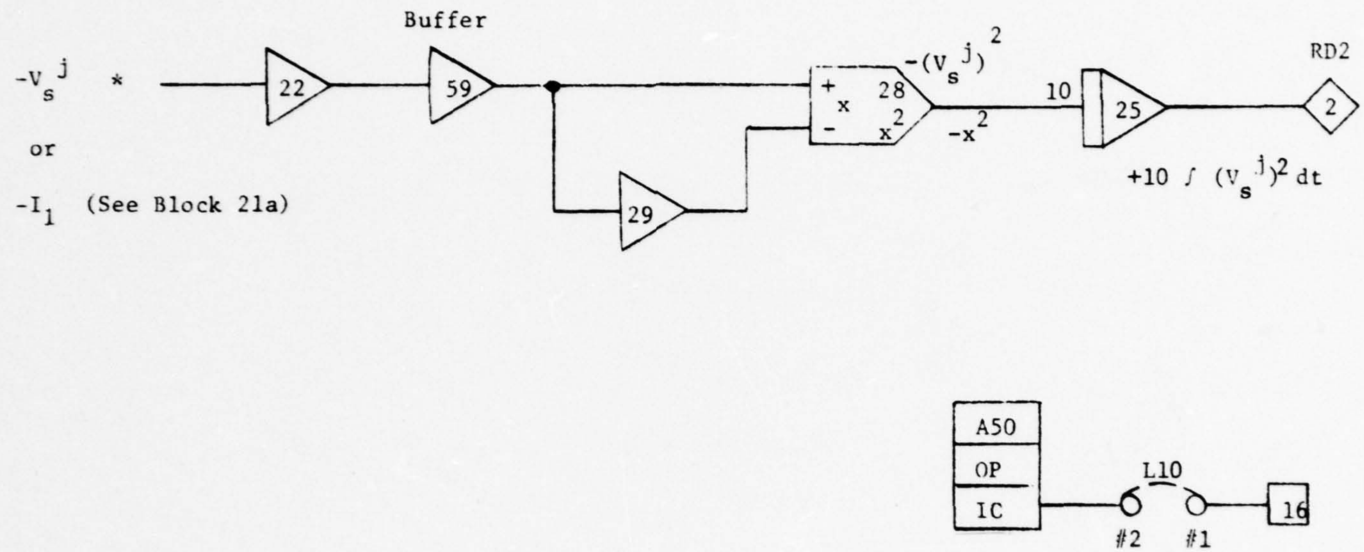
Block 23, Integrating Wattmeter

See discussion related to Block 13.



BLOCK 22

Ship Drag Correction Factor (Console 2)



*This point is connected to the arm of Relays 29A, 114A, 54A and Amplifier A85 according to the energy measurement to be made.

BLOCK 23

Integrating Wattmeter (Console 2)

X. REGENERATION CONTROL BY DYNAMIC BRAKING OF MOTOR

As previously mentioned, the use of dynamic braking of the motor provides a sink for the regenerated energy in the dynamic braking resistors. By maintaining the terminal voltage of the generator at or near zero, it is possible to prevent energy from being transferred to the generator and causing an overspeed trip. The purpose of this section is to describe in detail how this type of regeneration control is implemented in the computer simulation.

The sequence of operations commences with the occurence of the SM logic signal at the output of register OC in Block 8. This register becomes set whenever the logical conditions occur

$$(\omega_m > \alpha_\omega) \cdot (\tau_{RF} < 0) + (\omega_m < \alpha_\omega) \cdot (\tau_{RF} > 0)$$

where ω_m = per unit, motor speed

τ_{RF} = per unit, torque reference

α_ω = per unit, absolute value of motor speed below which the speed is considered to be zero.

The SM (stop motor) signal opens electronic switch 84 [8]* which disconnects the torque reference signal. This is equivalent to a zero torque reference so that the armature current will decay to zero according to the dynamics of the system.

Comparator 99 [8] is at all times sensing the magnitude of the armature current. When the value falls below the value α_I set

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*The bracketed 8 shows that the electronic switch appears in Block 8 of the program. Similar convention will be followed to relate other components to the program block in which they appear.

by pot P99 [8], comparator 99 [8] produces a one input to AND gate OF [8]. The value α_I is the zero current threshold.

The other two inputs to AND gate OF [8] are high so that register 1A [8] becomes set which in turn sets register OD [8] through differentiator OO [8]. Regarding the other inputs to OF [8], the SM signal enables the gate only when the regeneration cycle is in operation, and if push button PB05 [15] is low the gate is enabled. PB05 is used to determine whether the regeneration control will be dynamic braking or generator acceleration plus mechanical braking. Obviously, when PB05 = 0, the control is dynamic braking.

When register OD [8] goes high, the armature circuit is opened. To see how this happens, follow the logic level OD to Block 17. This sets registers 3A [17], 3B [17], 3C [17], 3D [17] and 4A [17] which in turn de-energizes relays R29, R114, R54, R84 and R24. These relays open the circuit breakers in the armature circuit as may be seen from Block 21.

After the armature circuit is opened, the mode of control of the generator is switched from current feedback to voltage feedback. To see how this happens, note that when register OB [8] is set, relay 49 is energized which switches the feedback signal to the generator terminal voltage. Register OB [8] is set by AND gate 1B [15] which is part of an OR circuit. One input to the OR circuit is register OD [8], so that voltage feedback occurs every time this register goes high. The other input to the OR circuit is AND gate 4F [15] which provides a logic one only when the regenerative control mode is generator acceleration plus mechanical braking. This particular mode is discussed in Section XI and need not concern us here.

The reference for the voltage feedback mode is obtained from amplifier A45 [15] which is zero. This is because integrator A45 [15] is in the operate mode, and there is feedback around it via pot P47 [15]. As a consequence the terminal voltage of the generator diminishes to zero in accordance with the dynamics of the generator field control system.

While this is going on, comparator 104 [8] is sensing the absolute value of the generator terminal voltage and goes high (a logic one) when the voltage falls below α_V which is the zero-voltage threshold set by P104 [8]. This event causes register 1B [8] to go high which resets register OD [8]. This in turn initiates reclosure of the armature circuit through the dynamic braking resistors.

To understand the event sequence involved in reclosure of the armature circuit, we must turn our attention to Block 17. When register OD [8] is reset, the AND gates 3D [17], 3E [17], 3F [17], 3A [17] and 4A [17] are enabled by the logic signal $\overline{OD}$. As these AND gates go high they will reset the registers which they drive and cause the corresponding armature circuit breaker to close. Consequently, we must consider the events which lead to the AND gates going high.

From Block 17 we see that the output of A32 [17] is $(V_{tg} - V_{tm})$ which is the voltage drop across the dynamic-braking resistor network. The output of P116 [17] is $I_g (R_g + R_m)$ which is simply the voltage drop caused by the armature current flowing through the armature resistances internal to the machines. The net input signal to A102 [17] is

$$E_t = V_{tg} - V_{tm} + I_g (R_g + R_m)$$

which is recognized as $E_g - E_m$. That is the difference between the internal generated voltage of the generator and motor. Figure 10.1 is useful in clarifying these relations.

Evidently E_t is the Thevenin voltage of the armature circuit (neglecting armature inductance) and is the voltage which drives the armature current through the total armature impedance.

The output of A100 [17] is proportional to the absolute value of the Thevenin voltage, and it is on the basis of this voltage that the dynamic braking resistors are switched into the armature circuit.

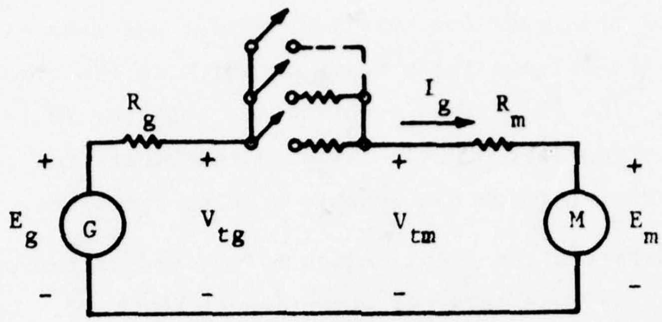

Figure 10.1. Diagram Showing Voltages and Current Associated with the Reclosure of the Armature Circuit.

Comparators 19 [17], 49 [17], 79 [17], 104 [17] and 109 [17] all are driven by the output of A100 [17]. The other input to these comparators are driven by individual pots which determine the level of the Thevenin voltage E_t *at which the dynamic braking resistors are* connected. As each resistor is connected the value of E_t diminishes so that a chain reaction occurs which finally results in closure of the final short-circuiting switch in the armature circuit.

The procedure for determining the voltage levels at which the dynamic braking resistors are to be connected and the value of the resistors themselves is the subject of Section XII-a of this report.

Because the generator terminal voltage is held at zero (approximately) by control action, the reclosure of the armature circuit will result in driving the motor speed to almost zero. Only the internal motor armature resistance prevents the speed from actually becoming zero.

Referring to Block 8, AND gate OE [8] generates the logic level ZS (zero speed) which causes AND gate 5E [9] to go high. This event *coupled with the closure of the armature shorting switch causes* AND gate 5D [9] to go high which by means of the OR circuit associated with AND gate 5A [9] delivers a logic one to AND gates 2F [8] and 1F [8].

At this point it is appropriate to reset the Regeneration Control Circuit provided the new torque reference signal has the proper relation to the torque which is required to hold the motor at zero speed. If the zero-speed motor torque is τ_m, the logic conditions for resetting the control are

$$(\tau_{RF} > 0) \cdot (\tau_m < \tau_{RF}) + (\tau_{RF} < 0) \cdot (\tau_m > \tau_{RF})$$

These logical relationships are implemented by comparator 44 [8] and AND gates 2F [8], 1F [8] and 2E [8].

Block 8 shows that when the reset line goes high, registers 1B [8], 0B [8], 0C [8] and 5A [9] are all reset which returns the Regeneration Control back to its original state.

XI. REGENERATION CONTROL BY ACCELERATION OF THE TURBINE-GENERATOR ROTATING INERTIAS

The purpose of this section is to explain how this mode of operation is implemented in terms of the computer simulation hardware. There are two basic phases to the regeneration control. The first is to slow the generator down to a predetermined low speed. The second is to stop the motor in such a manner that the resulting regenerated energy speeds up the turbine but does not cause an overspeed trip.

A generator brake is an essential part of the control for two reasons. It is necessary to reduce the speed of the generator in the first place, and it is necessary to prevent overspeed if the regenerative energy is excessive.

Since the brake must in one way or another absorb all the regenerated energy it might seem that there is no particular advantage in slowing the generator down and then permitting it to speed up. This is true except for the fact that the system reduces the peak power requirement of the brake. Otherwise, one might just as well use the brake to hold fixed generator speed.

The present option for regeneration control is brought into operation by setting push button PB05 [15] = 1. Referring to Block 15, this causes the following things to happen:

(a) AND gate OF [8] is blocked which prevents the armature circuit from opening and precludes the dynamic braking option.

(b) Relay 119 [11] is closed which permits the braking torque when present to be applied to the turbine-generator rotating inertia.

(c) AND gate 4C [12] is activated which permits a speed error signal to produce a braking torque.

(d) AND gate 4D [15] is activated causing integrator A45 [15] to follow the generator voltage except when the voltage feedback mode obtains.

(e) AND gate 4F [15] is activated which controls the voltage-feedback mode. Voltage feedback takes place when the following logical condition are simultaneously satisfied:

$$(|I_g| < \alpha_I) = 1$$

$$(|V_{tg}| < \alpha_V) = 1$$

$$(\omega_g < \omega_R') = 1$$

$$SM = 1$$

These are all self evident from Block 15, AND gate 4F [15].

(f) AND gate 5F [9] is activated which controls the termination of the regeneration cycle.

(g) AND gate 5B [9] is activated which initiates the generator brake control when the SM signal occurs.

The generator brake operates in a manner so as to reduce the generator speed from its normal value ω_R to a new lower value $\omega_R + \Delta\omega_R^*$. This reduction in speed occurs simultaneously with the unloading of the generator when the SM signal occurs. Details of the operation are shown on Block 9. It is assumed through this discussion that PB5 = 1.

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*$\Delta\omega_R$ is a negative number.

When the SM signal occurs AND gate 5B [9] goes high which sets register 5A [9] which in turn generates a pulse through differentiator 40 [9] setting register 5B [9] which produces the logic signal RGS (reduce generator speed). In response to RGS = 1, relay R59 [9] closes which changes the generator speed reference signal by $\Delta\omega_R$. This signal is numerically a negative value and when added to the normal reference reduces the net reference signal. Q27 [9] controls the change in reference and Q09 [9] controls the rate at which the reference is changed. Signal $\Delta\omega_R$ is added to ω_R (the normal speed reference) at A31 [12].

The advent of the negative speed error causes the generator brake to come on and reduce the generator speed to $\omega_R + \Delta\omega_R$, the new reduced speed reference.

It is necessary to determine when the generator speed actually reaches its reduced value. This is accomplished by comparator 54 [9] which has two inputs. The first is $-\omega_g$ the actual generator speed and the second is $\omega_R' = 1.05\ (\omega_R + \Delta\omega_R)$. When the actual speed, ω_g, drops below 1.05 times the new speed reference, the system considers that the generator speed has been adequately reduced and that it is safe to proceed with the regeneration cycle. Consequently when AND gate 4F [15] is enabled by comparator 54 [9] and the other conditions are met, the voltage feedback mode is initiated by setting register OB [8].

When voltage feedback occurs, integrator A45 [15], which carries the voltage reference, goes to zero and the speed of the motor will also go to zero. This causes regeneration of the kinetic energy of the motor and propeller inertia plus a certain amount of water power. The regenerated energy is supposed to reaccelerate the turbine-generator inertia so that the brake must be made non-responsive to the resultant speed error. This comes about via AND gate 3F [9] which energizes R19. As shown in Block 12 when R19 [9] is energized (high) the brake reference signal is disconnected so that the braking effort is reduced to zero. This occurs coincidentally with the occurrence of the voltage feedback mode via register OB [8] which provides an input to AND gate 3F [9].

If during regeneration the generator speed remains less than the normal reference speed the brake remains unactivated. However, if the speed should exceed the normal reference, comparator 39 [9] will go high causing AND gate 3F [9] to go low reapplying the braking effort.

When the motor speed reaches zero, AND gate 5C [9] goes high which de-energizes R59 [9] and R19 [9]. This returns the speed reference to normal and applies the brake error signal once more. Of course, if the generator speed is less than the reference speed, no braking will occur and fuel will be applied. On the other hand, if the speed should still be greater than normal, the brake will bring it to the normal value.

AND gate 5C [9] also activates AND gate 5F [9]. When 5F [9] goes high, the regeneration cycle terminates. However, this is not permitted until the fuel rate exceeds a minimum value, W_M, which is set by P65 [9]. This prevents the load from being applied to the generator with idle fuel flow. If this happens, the generator speed will collapse because the fuel valve cannot be opened quickly enough to supply the load power requirements. The fuel flow must always supply the generator losses in the voltage feedback mode. This is a direct result of the fact that the voltage feedback control keeps the terminal voltage of the generator at zero.

When AND gate 5F [9] finally goes high, the regeneration cycle is terminated resulting in the reset of registers 5A [9], OB [8] and OC[8].

XII. COMPUTER RECORDS

(a) Design of Dynamic Braking Resistance Network

In Section VI the theoretical basis of dynamic braking is discussed. The mathematical results which were obtained assumed that the propeller torque-speed characteristic is linear for the regenerative segment. This is not exactly true. Furthermore, it was assumed that the self inductance of the armature circuit is not important. This also is not a completely valid assumption particularly when the final switches are closed.

To obtain the best possible design for the dynamic braking resistor network,these factors should be included which requires machine calculation. The analog computer simulation provides this capability.

The basic constraints on the design are:

1. The resistor bank should have no more than five switches or resistor steps.
2. The peak current when each switch is closed should be limited to a fixed value.

The limit on the number of switches and the peak armature current has an important influence on the motor speed at which dynamic braking can be started. From the discussion of Section VI it should be clear that more steps are required when the initial speed is higher because of the limitation on the maximum allowed current. Therefore the number of allowed steps and the maximum allowed armature current determines the motor speed at which dynamic braking can be started. This in turn has a very profound influence on the distance required to stop the ship because until dynamic braking occurs the ship is slowing down only as a result of the hydrodynamic drag on the hull.

A method for determining the dynamic braking resistors and the voltage at which they should be connected will now be described. The method is an iterative method whereby one determines the maximum initial propeller speed (and corresponding ship speed) at which the dynamic braking can be carried out in five steps without exceeding the maximum armature current on any step.

To implement the procedure, one fixes the ship speed by removing propeller torque from the hull by setting P75 [4] to zero, and applying an external thrust via Q17 [4]. This enables one to run the ship at any arbitrary speed. To make the ship speed respond quickly to changes in the setting of Q17 [4], pot P16 [4] should be set at 1.000. This is equivalent to reducing the mass of the ship.

The propeller will now turn at a speed determined by the fixed ship speed and the torque of the drive motor. If the armature circuit is opened, then the motor will attain the windmill speed corresponding to the ship speed. Let us assume that the computer is initialized with voltage feedback around the generator and an open armature circuit. One can manually close the dynamic resistor switches and observe on a recorder the resulting armature current and the propeller speed. For example, when R29A [21] is closed the first dynamic braking resistor is put in the circuit. By repeatedly inserting R_4 into the circuit and adjusting the value of R_4 by pot Q27 [21], one can arrive at a resistance value which gives a current pulse with exactly the maximum allowable value. After this is accomplished, relay switch 29A [21] is closed, and the same procedure repeated with relay R114A [21] which inserts the second dynamic-braking resistor, R_3. Continuation of this procedure will yield acceptable values for R_4, R_3, R_2 and R_1 in that order. The next switch to close is R24A [21] which short circuits all of the dynamic braking resistors. The closure of this switch will result in a current pulse which is either less than or greater than the maximum allowable value. If the pulse is too great, then the ship speed must be reduced or the maximum current must be increased. Presumably the ship speed would be reduced. A repeat of the above process for different

ship speeds will ultimately yield a speed at which all the current pulses which occur when the switches are consecutively closed will have peak values equal to the maximum value allowed. Between each switch closure it is assumed that the propeller speed is permitted to come to equilibrium.

Figure 12.1 shows the actual computer records for the Full-Power Configuration with a peak current of 25,800 amperes. The bottom trace is the generator armature current pulses which are negative

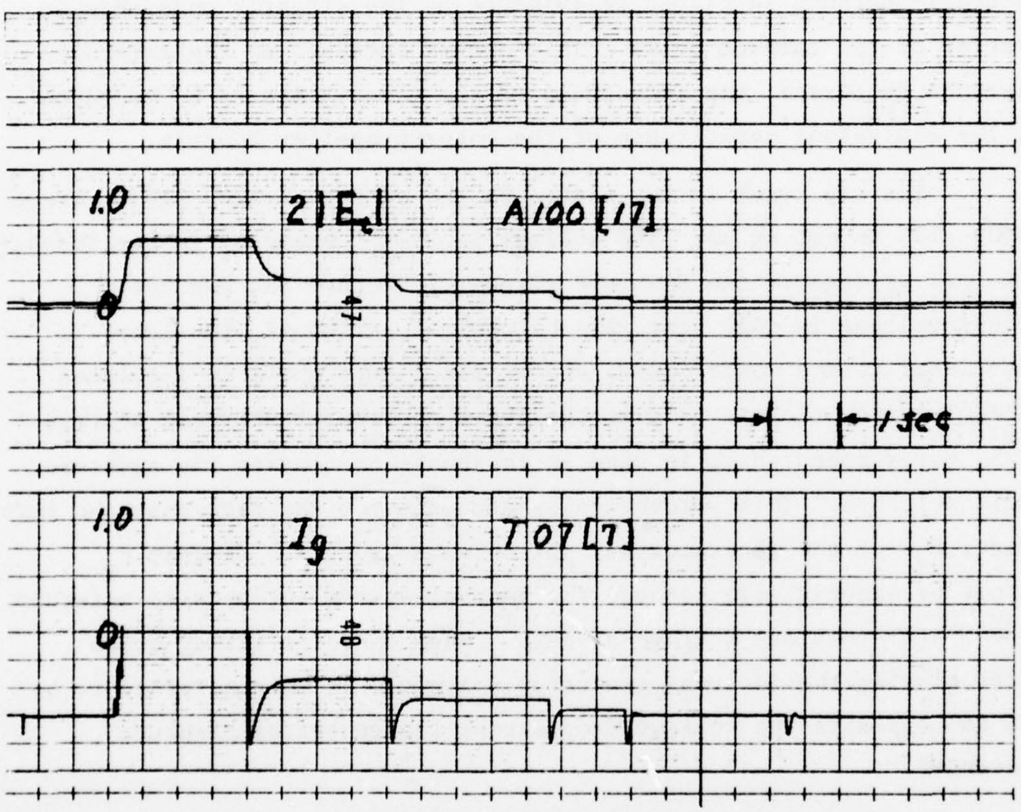


Figure 12.1. Performance of Dynamic Braking Resistors.

because the motor is rotating in the positive direction. Notice that the first four relay closures produce the same pulse amplitude. The final relay closure is the shorting switch which does not produce quite the maximum pulse amplitude. Further increase in the ship speed and adjustment of the braking resistors could bring this pulse up if desired. However, this was considered unnecessary. Observe that the

level of the current becomes more negative after each switch closure. This current supplies the torque at the equilibrium speed which results.

The time scale on the record is two vertical lines per second. In slightly more than half a second after the first switch closure the equilibrium speed is attained. Also the time to reach equilibrium decreases after each switch closure as was determined in Section VI.

When the last two switches are closed, the influence of the armature inductance is placed in evidence by the slightly under-damped character of the current pulse. This occurs because, as the armature resistance decreases, the inductance of the circuit starts to resonate with the equivalent capacitance of the motor-propeller inertia.

The top trace in the figure is the output of A100 [17]. Since pot Q04 [17] is set at .5, this voltage is 2 $|E_t|$ where E_t is the Thevenin equivalent voltage of the armature circuit. Because the generator terminal voltage is held near zero by control action, E_t is almost proportional to the motor speed, and as the figure shows it decreases with each switch closure. It is the Thevenin armature-circuit voltage not the motor speed which is used as the basis of closing the armature circuit switches. This automatically accounts for the fact that the internal voltage, E_g, of the generator may not be exactly zero. In fact E_g will not be exactly zero because the control system attempts to maintain the generator terminal voltage at zero. When there is steady-state current flowing the internal generator voltage will be controlled to be equal and opposite the voltage drop across the generator armature resistance.

The closure of the dynamic-braking resistor switches must coincide with the asymptotic values of A100 [17]. This determines the setting of pots P19 [17], P49 [17], P79 [17], P104 [17] and P109 [17] The following table gives the pot settings which determine the dynamic-braking resistors and the voltage at which they must be switched into the circuits.

Comparator Bias Pot Setting		Switching Voltage A100 [17]	Dynamic Resistance Pot Setting	Reciprocal of Dynamic Resistance*	Energy Loss*
P19 [17]	=	.6151	Q27 [21] = .0365	$1/R_4$ = 3.65 pu	$W(R_4) = 52.8 \times 10^{-3}$ pu
P49 [17]	=	.2481	Q29 [21] = .0698	$1/R_3$ = 6.98 pu	$W(R_3) = 8.38 \times 10^{-3}$ pu
P79 [17]	=	.1428	Q09 [21] = .1431	$1/R_2$ = 14.31 pu	$W(R_2) = 2.075 \times 10^{-3}$ pu
P104 [17]	=	.0896	Q22 [21] = .0562	$1/R_1$ = 56.2 pu	$W(R_1) = .498 \times 10^{-3}$ pu
P109 [17]	=	.0551	--	--	--

*Base ohms is .128 ohms and base energy is 85.4×10^6 joules if dynamic resistors are associated with each motor. See Section VIII, Base Set I: Full-Power Configuration, Var I.

Having determined the dynamic-braking resistors and the voltage at which the resistors are to be connected, the simulation can be returned to its normal state, and the energy loss in the dynamic resistors may be measured during a regeneration cycle. The only precaution to take in this is to make sure the initial ship speed is high enough to produce an output on A100 [17] greater than .6151. Otherwise an abridged regeneration cycle will occur, and the energy measurements will be too low for some of the resistors.

The fourth column of the above tabulation gives the measured value of the energy loss in each resistor. These measurements are made by using the integrating wattmeter circuit which is found in Block 23. This circuit calculates ten times the integral of the square of whatever signal is applied to the input of A22 [23]. Consequently, if the circuit input is connected to the arm of relay 29A, then the output of A25 [23] will be ten times the integral of the squared voltage across R_4. Dividing this quantity of $10 \cdot R_4$ yields the energy dissipated in R_4. This assumes that the integrator is in operate during the regeneration cycle.

In a similar manner one can measure the energy loss in each of the dynamic-braking resistors. In the case of resistor R_1 one measures the integral of the current squared by connecting the wattmeter to A85 [21].

It should be noted that resistor R_1 [21] has an inductance in series with it. In the present example under discussion, the inductance value is so small as to be inconsequential, and for this reason has not been mentioned until this point. The reason that the program has the capability of placing the inductance in series with the resistor is to provide a means for limiting the current pulse when the final resistance is connected. This enables one to limit the number of steps in some cases where more than five steps would otherwise be required. Unfortumately the use of series inductance with the dynamic-braking resistor is not a cure-all because the reactor which is required to realize the inductance may be completely unrealistic in terms

of physical size and cost. In the present case we solved the problem without any inductance at all.

A dynamic-braking resistor network was also determined for the quarter-power configuration by the same methods outlined above. Once again the design was achieved without a reactor in series with the final resistor. The following tabulation gives the design details for the quarter-power case.

Comparator Bias Pot Setting		Switching Voltage A100 [17]	Dynamic Resistance Pot Setting	Reciprocal of Dynamic Resistance*	Energy Loss*
P19 [17]	=	.3303	Q27 [21] = .0600	$1/R_4 = 6.00$	$W(R_4) = 32. \times 10^{-3}$
P49 [17]	=	.1341	Q29 [21] = .1228	$1/R_3 = 12.28$	$W(R_3) = 4.92 \times 10^{-3}$
P79 [17]	=	.0756	Q09 [21] = .2433	$1/R_2 = 24.33$	$W(R_2) = 1.22 \times 10^{-3}$
P104 [17]	=	.0486	Q22 [21] = .0873	$1/R_1 = 87.3$	$W(R_1) = .23 \times 10^{-3}$
P109 [17]	=	.0350	--	--	--

*For motor: Base ohms = .1915Ω, Base energy = 57.0×10^6 joules. See Section VIII, Base Set IV: Quarter-Power Configuration, Var II (Series Motors)

XII. COMPUTER RECORDS (CON'T)

(b) Dynamic Braking; Quarter-Power Configuration

In Section XII-a it was shown how to set up the dynamic-braking resistance network. We now examine system performance for the quarter-power configuration. Specifically we shall consider the quarter-power configuration where the motors are connected in series as shown in Section VIII, Fig. 8.3. It turns out that the quarter-power configuration with the motor connected in parallel (Section VIII, Fig. 8.2) is not practical since it requires steady-state generator current beyond its rating. As a result the series motor connection is the only one which we shall consider. The appropriate base quantities for this configuration are given by Base Set IV: Quarter-Power Configuration, Var II (Series Motors) in Section VIII.

When the base quantities are changed, the pots which determine the generator and motor electrical and mechanical constants must be reset. Also the pot or pots which convert the physical propeller torque to per unit motor torque and that which converts physical turbine torque to per unit generator torque must be reset. For convenience the following list of the pots which must be changed has been prepared:

P13 [1]	$2 \times 10^5/(10 \times$ Base gen. torque in lb $\cdot$ ft)
P71 [2]	Turbine-generator inertia/(10 x Base generator inertia)
P95 [2]	Generator armature resistance/Base generator ohms
Q12 [2]	Generator damping/Base damping
P11 [3]	Motor-propeller inertia/Base motor inertia
P38 [3]	Motor armature resistance/Base motor ohms
P107 [5]	$(2 \times 29.3 \times 10^6/5)/(10 \times$ Base motor torque in lb $\cdot$ ft)
P29 [16]	Set same as P107 [5]
P116 [17]	P95 [2] + P38 [3]

P19 [17] P49 [17] P79 [17] P104 [17] P109 [17]	These pots determine the switching voltages of the dynamic-braking resistors. Values are determined in accordance with Section XII-a.
P55 [21]	10^{-4} [(Gen. armature inductance/Gen. base henries) + (Motor armature inductance/Motor base henries)]
Q27 [21] Q29 [21] Q09 [21] Q22 [21] Q24 [21]	These pots determine the dynamic-braking resistance network. Values are determined in accordance with Section XII-a.

Regarding the pots in Block 21 associated with the dynamic braking resistors, one can consider the resistance networks to be associated with either the motors or the generators. If one knows the per unit resistance values, the actual ohms are determined by multiplying by the base ohms of the motor provided each of the two motors is to be equipped with a network. On the other hand, if the network is to be supplied with the generator the generator base ohms should be used. In a similar manner the per unit dissipated energy figures which are given in Section XII-a should be multiplied by the motor or generator base energy according to whether each motor will have its own network or the generator will have the network.

For the quarter-power configuration the following values have been determined for the pots previously listed:

P13 [1]	= .1000	P49 [17]	= .1341
P71 [2]	= .0196	P79 [17]	= .0756
P95 [2]	= .0046	P104 [17]	= .0486
Q12 [2]	= .0000	P109 [17]	= .0350
P11 [3]	= .0567	P55 [21]	= .2020
P38 [3]	= .0123	Q27 [21]	= .0600
P107 [5]	= .584	Q29 [21]	= .1228
P29 [16]	= .584	Q09 [21]	= .2433
P116 [17]	= .0169	Q22 [21]	= .0873
P19 [17]	= .3303	Q24 [21]	= 1.0000

The settings of other pots which are independent of the base quantities are shown in the computer block diagram. All other pot settings shown on the Block diagrams are for the Full-Power Configuration, Var I, (see Section VIII). To further complicate matters there are several other pots which may be changed to modify (improve) the dynamic performance of the system. The function of these will now be described.

P00 [1]:

Pot P00 sets the idle fuel flow to the turbine. This pot should be set so as to provide zero torque at the minimum speed at which the turbine is expected to run. To understand the reason for this, we refer to Fig. 12.2 which shows a sketch of the turbine torque versus speed for different fuel flow values.

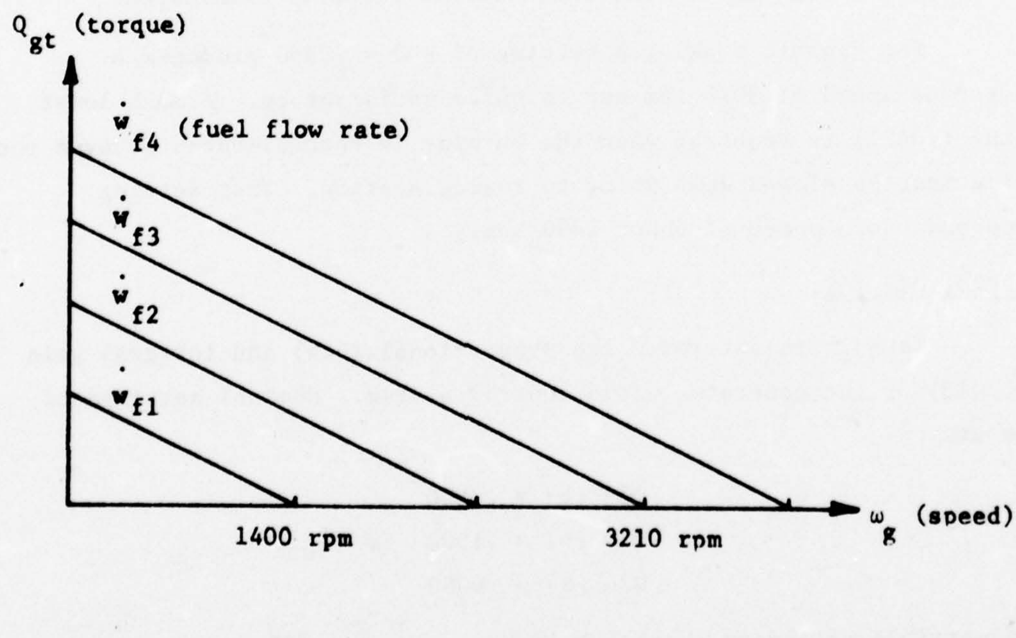


Figure 12.2. Turbine Torque vs. Speed for Various Fuel Flow Rates.

Suppose for the dynamic braking case the turbine should run at 3210 rpm. Theoretically the speed should always be this value. In this case one would adjust the minimum fuel flow to $\dot{w}_{f3}$. Suppose the minimum fuel flow were adjusted to $\dot{w}_{f1}$. During a regeneration cycle the main fuel valve is closed so that the fuel flow will go down to $\dot{w}_{f1}$ although the turbine is actually turning at about 3210 rpm. When the torque reference is reapplied, the generator is immediately required to supply power. This causes a speed error (a droop in generator speed) which starts to open the fuel valve. Because the rate at which the fuel valve can open is quite slow no significant torque can be developed by the turbine until the turbine speed droops almost to the value corresponding to the intercept of the $\dot{w}_{f1}$ characteristic with the speed axis. In this example, that is close to 1400 rpm. On the other hand, if the minimum fuel flow were set at $\dot{w}_{f3}$, the turbine would immediately start to deliver power and the large speed droop and the associated time delay in obtaining the required turbine power is eliminated.

For dynamic braking a setting of P00 = .0880 produces a zero torque speed of 3010 rpm and is quite satisfactory. A much lower setting (.0402) is required when the turbine is reaccelerated because the turbine must be slowed down prior to reacceleration. This setting corresponds to a speed of about 1400 rpm.

Q24, P20, Q19 [6]:

These pots determine the proportional (Q24) and integral gain (P20, Q19) of the generator field control system. Nominal settings of these are

Q19 [6] = .0800
P20 [6] = .1000
Q24 [6] = .6000

It is possible to change these values by at least ± 50% and still have excellent response of the field control system. For the quarter-power configuration with dynamic braking the values indicated above were used.

With the quarter-power configuration the full ahead condition occurs when the lone gas turbine and associated generator is delivering full power. Under this condition the following steady-state measurements have been made:

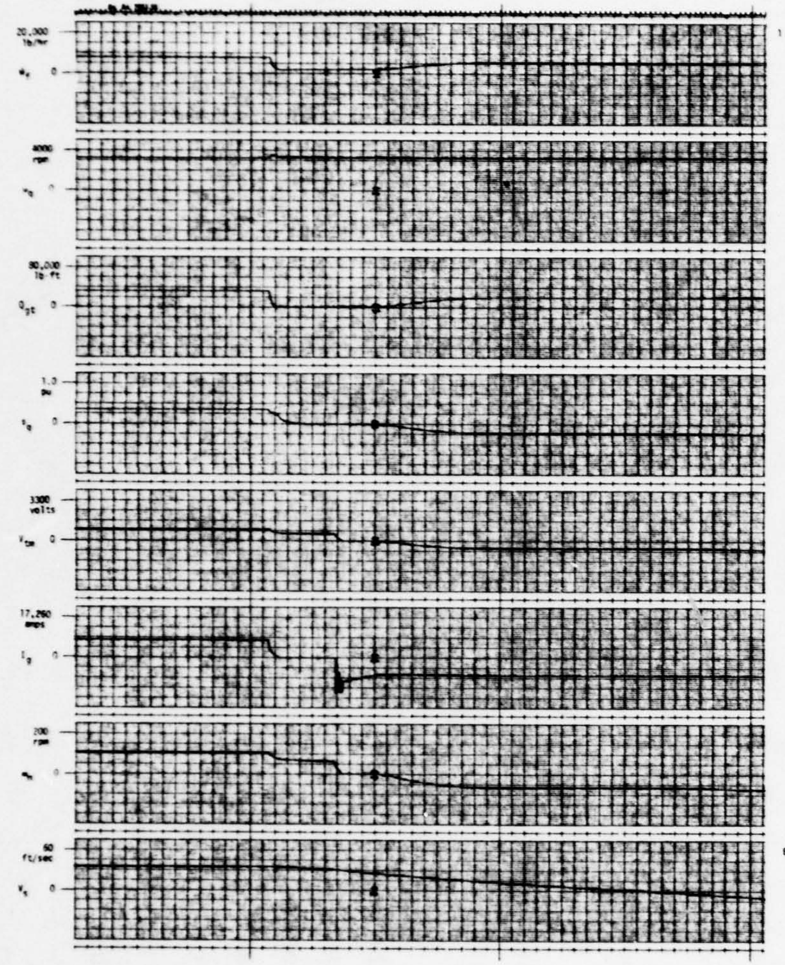
Component	Variable	Value in pu	Physical Value
A91 [2]	V_{tg}	.2894	1910 volts
A20 [4]	$V_s/60$	.5965	V_s = 35.6 ft/sec
A10 [3]	ω_m	.5423	108.5 rpm
A42 [3]	ϕ_m	.5247	
A13 [3]	τ_m	.2289	$.459\text{x}10^6$ lb·ft
A94 [7]	I_m	.436	7530 amps
A43 [3]	$-E_m$	−.2841	938 volts
A98 [2]	$-E_g$	−.2915	1924 volts
A16 [4]	$D_s/10^6$	.2352	$D_s = .2352\text{x}10^6$ lbs
A24 [5]	$\sin\theta$	.6290	
F52 [5]	$5\ C_Q$	.1346	
F32 [5]	C_T	.1089	
A33 [5]	$-T/(2\text{x}1.83\text{x}10^6)$	−.0317	$T = .116\text{x}10^6$ lbs
A103 [5]	$-5Q/(2\text{x}29.3\text{x}10^6)$	−.0394	$Q = .462\text{x}10^6$ lb·ft
A00 [1]	$\dot{\omega}_f/(2\text{x}10^4)$	.3948	$\dot{\omega}_f$ = 7890 lb/hr
A66 [1]	$Q_{gt}/(2\text{x}10^5)$	.1590	$Q_{gt} = .318\text{x}10^5$ lb·ft
P13 [1]	$\tau_t/10$	.0159	$\tau_t = .318\text{x}10^5$ lb·ft
A68 [2]	$-\tau_g$	−.1589	$.318\text{x}10^5$ lb·ft
A70 [2]	ω_g	.8026	3210 rpm
P22 [14]	Torque ref. level	.2301	
Q22 [14]	Torque ref. level	.2301	

Not only is the steady-state performance of interest, but also the detailed dynamic performance in crash back or other maneuvers is of great interest. A crash-back maneuver is performed by starting in the steady-state full-ahead condition. There is a specific torque reference signal corresponding to this which happens to be P22 [14] = .2301 as indicated in the listing above. The crash-back maneuver is performed by using the Alternate Rate-Limited Torque Reference Input Circuit of Block 14. By setting relay R24A [14] in the positive position, the reference torque is reversed provided Q22 [14] is set at .2301. This starts the regeneration cycle and ultimately applies the reverse reference signal to the system. The propeller reverses direction of rotation, and in due-course the ship stops and commences to reach a steady-state speed in the reverse direction.

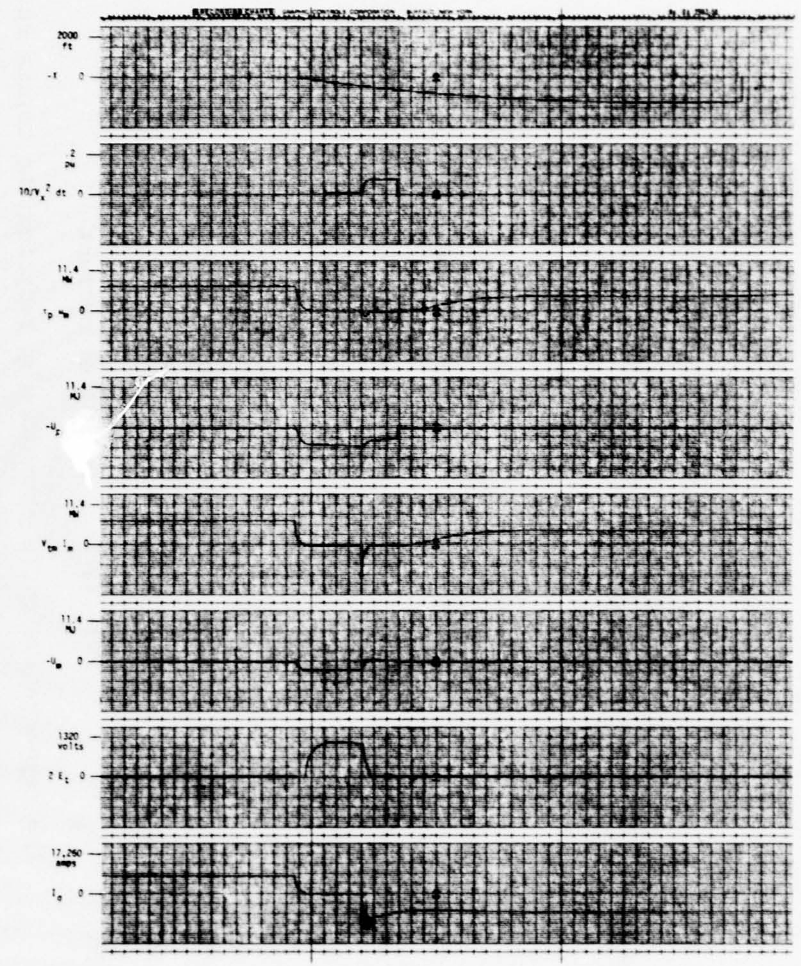
Computer Record 12.3 shows the detailed response of the system. This record as others to be discussed consists of 16 Channels. The first eight are on the (a) record and the second eight are on the (b) record. One second timing pulses will be found at the top of each record. A common trace on the (a) and (b) records is the generator current I_g.

Each channel is labeled to identify the variable, and the scale zero point and the value corresponding to +20 lines is indicated. The various variables which are displayed have the following definitions:

Channel	Variable Symbols	Computer Source	Definition
1	$\dot{w}_f$	A00 [1]	Turbine fuel flow rate
2	ω_g	A70 [2]	Generator speed
3	Q_{gt}	A66 [1]	Turbine torque
4	ϕ_g	A12 [2]	Generator flux
5	V_{tm}	A41 [3]	Motor terminal voltage
6	I_g	A94 [7]	Generator current
7	ω_m	A10 [3]	Motor speed



(a)



(b)

RECORD 12.3

QUARTER - POWER CONFIGURATION # DYNAMIC BRAKING
FULL AHEAD TO FULL ASTERN
L81(6) = ± 1.00; MAXIMUM TORQUE REFERENCE SLEW RATE = 1 PU/SEC
P00(1) = .0880; MINIMUM FUEL FLOW = 1760 LB/HR

Channel	Variable Symbols	Computer Source	Definition
8	V_s	A20 [4]	Ship speed
9	X	A20 [4]	Ship travel
10	$\int V_x{}^2\ dt$	A50 [23]	Integrating wattmeter
11	$\tau_p\ \omega_m$	T06 [16]	Propeller power
12	U_p	A17 [16]	Propeller energy
13	$V_{tm}\ I_m$	T15 [19]	Motor power input
14	U_m	A105 [19]	Motor input energy
15	$2\ E_t$	A100 [17]	Armature circuit Thevenin voltage
16	I_g	T07 [7]	Generator current

The regenerative cycle commences by reducing the torque reference to zero. This causes the armature current to decay to zero which unloads the generator. Unloading the generator in turn causes its speed to start to increase which produces a speed error resulting in closure of the turbine fuel valve. The amount of speed error which results depends upon how fast the generator is unloaded and how quickly the fuel valve can respond to the speed error.

After the armature current is reduced to nearly zero, the armature circuit is opened as can be seen from the discontinuity in the I_g trace.

Next the voltage of the generator is reduced to zero as evidenced by the ϕ_g trace. The motor terminal voltage and motor speed continually decrease while all the preceding operations are going on because of loss of torque on the propeller. Ultimately the propeller reaches the so-called windmill speed which continuously decreases as the ship slows down under the influence of the hydrodynamic drag forces.

When it is detected that the generator terminal voltage has reached zero (within certain predetermined limits) the armature circuit

is reclosed through the dynamic braking resistors. This results in the current pulses shown in the I_g trace and also reduction of the motor speed to nearly zero as the ω_m trace shows. During this period regeneration of power from the motor is occurring as may be seen by the fact that motor terminal voltage is positive while the armature current is negative. Also the trace of $V_{tm} I_m$ is negative. The fact that the generator terminal voltage is zero prevents the regenerated energy from accelerating the turbine as the ω_g trace clearly shows.

After the motor speed is detected to be zero, the way is then cleared to reapply the reference torque signal. The conditions which must be satisfied before this can occur are discussed in detail in Section V. In our particular case the new torque reference is one which will drive the ship full astern at a turbine power of 20,000 HP. This is applied as soon as zero propeller speed is detected.

Zero propeller speed, as referred to in this context, does not mean true zero speed. In fact as discussed in Section X, the propeller never comes to zero speed because of the residual armature resistance. Consequently there is a minimum absolute value of the speed below which the propeller is considered to be stopped. If one carefully inspects the current and speed traces, it will be observed that after the armature circuit is reclosed, the propeller speed continues to decrease until it reaches the zero-speed value at which time reverse reference is reapplied.

In assessing the performance of the system with dynamic braking, it is important to observe the change in speed of the generator, which in the present case is quite good except for the initial surge at the beginning. Also the distance the ship travels before coming to a stop is important. The X trace shows this to be about 1250 ft. One of the major factors which influence the stopping distance is the time at which dynamic braking commences. Inspection of the X trace shows that the ship has already traveled about 430 ft before dynamic braking starts. If dynamic braking is started sooner, the initial travel of the ship

will be reduced, and the overall travel distance will decrease. There is a price which must be paid to initiate dynamic braking earlier in the form of higher peak armature current.

The crash-back maneuver turns out not to be the most taxing on the system from the point of view of attempting to control regeneration. Record 12.4 shows what we shall call the regeneration maneuver. This is simply the initiation of the regeneration cycle (perhaps by reversing the torque reference as was done in Record 12.3) followed by a return to the initial full-ahead torque reference. Up to the point where the motor is brought to a halt, the traces are identical to Record 12.3. However, when the reference is reapplied, the armature current must go from a negative value to a positive value. Simultaneously with this the motor starts to rotate in the positive direction. (See the I_g and ω_m traces in Record 12.4). Consequently for a short period of time unavoidable regeneration occurs. The amount of energy associated with the regeneration depends upon how quickly the armature current can be reversed which in turn depends upon the basic speed of response of the torque control system and the permitted slew rate of the torque reference signal.

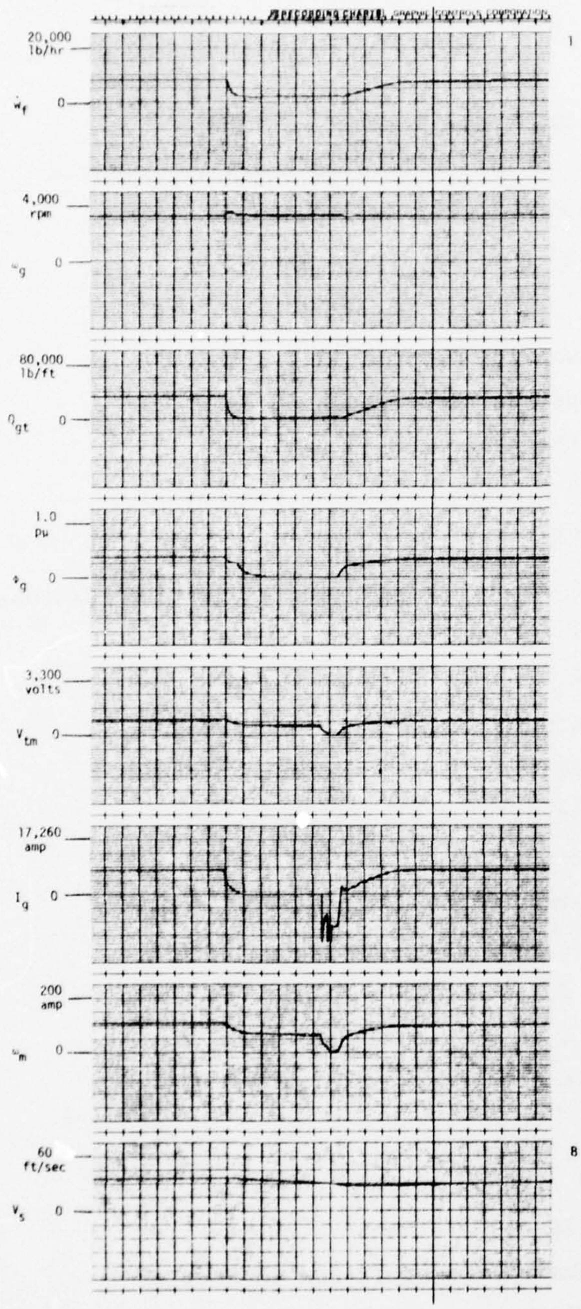
In Record 12.4 the small perturbation in generator speed associated with this unavoidable regeneration can be seen. Record 12.5 shows the influence of this phenomena in a much more dramatic manner. This is also a record of regeneration from full ahead but with the slew rate of the torque reference signal reduced to .2 pu/sec from 1 pu/sec as in Record 12.4. This is manifested by the much more gradual decrease in the generator load as the regeneration cycle commences. Because of this there is only a very slight initial speed increased of the generator since the turbine speed control system has plenty of time to respond to the speed error signal. On the other hand, when the torque reference is reapplied following dynamic motor braking, it takes several seconds for the current to go from the negative braking value to a positive value. Consequently there is much more regeneration which results in an appreciable increase in the generator speed. The speed increase is

followed by a large deceleration in turbine speed because as soon as the armature current goes positive an amount of turbine power is required which is inconsistent with the instantaneous fuel-valve opening. Eventually the fuel valve does open up and control of the generator speed is regained as the ω_g trace shows.

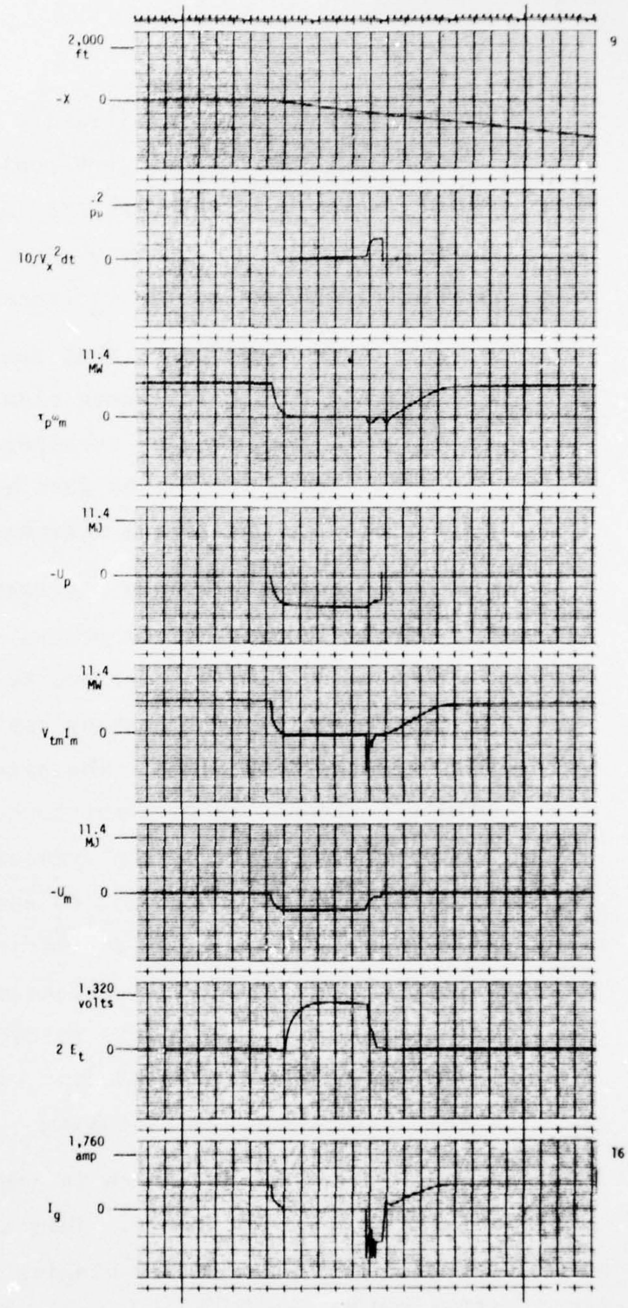
The conclusion that can be drawn from Records 12.4 and 12.5 is that the torque reference slew rate must be slow enough to prevent too much initial turbine overspeed when the generator is unloaded. On the other hand, it must be fast enough to prevent excessive turbine overspeed when the torque reference is not reversed.

In the previous discussion some of the record traces have been discussed in detail. Hopefully the others are self evident with the exception of Channel 10 ($10 \int V_x^2\, dt$) and Channel 14 ($2\, E_t$). Both of these channels relate to the dynamic braking resistor network which was discussed in detail in Section XII-a. The signal E_t is the Thevenin voltage of the armature circuit which prior to the regeneration cycle is simply the voltage drop caused by the armature circuit resistance. When the armature current is brought to zero, the Thevenin voltage goes to zero since the generator and motor internal voltages exactly cancel. When the armature circuit breakers open, E_t is simply the voltage across the breaker contacts. This voltage starts at zero and gradually increases because the generator voltage is brought to zero as a preamble to the dynamic braking.

Channel 10, which is labeled $10 \int V_x^2\, dt$, is the output of the integrating wattmeter. This circuit is used to measure the energy dissipated in the dynamic braking resistors as was explained in Section XII-a and is connected to the various resistors as required. For all the records covered in this report the input to the integrating wattmeter was attached to the arm of relay R29A [21] and measured the energy dissipated in dynamic resistor R_4. Integrator drift is clearly evident in the trace. This effect must be subtracted out in making energy measurements.



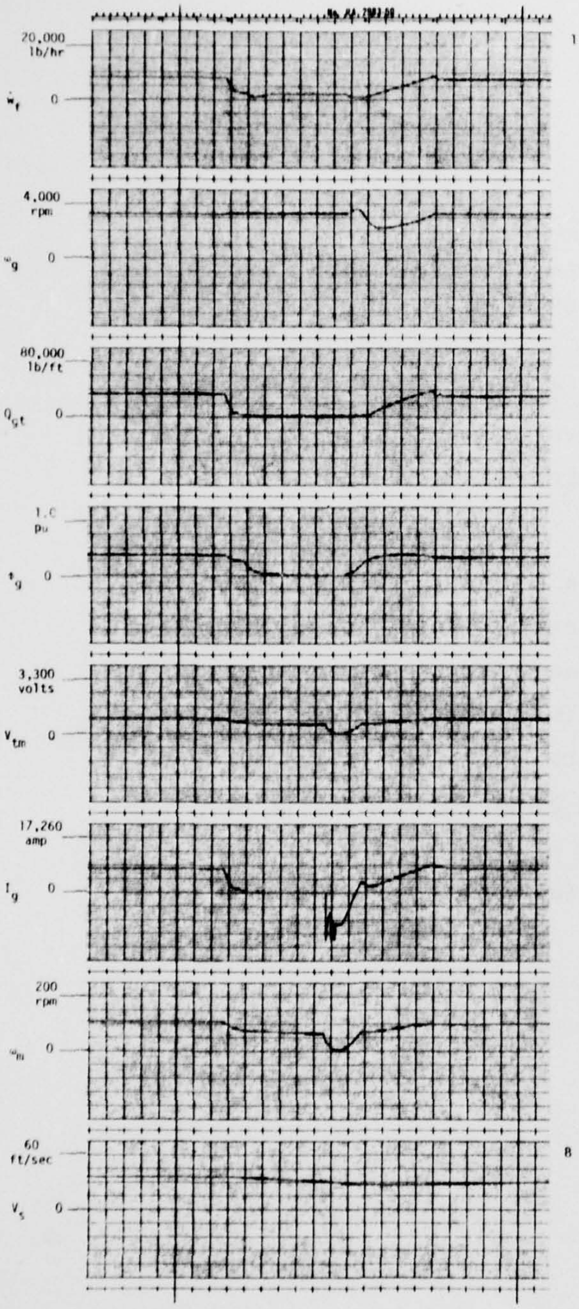
(a)



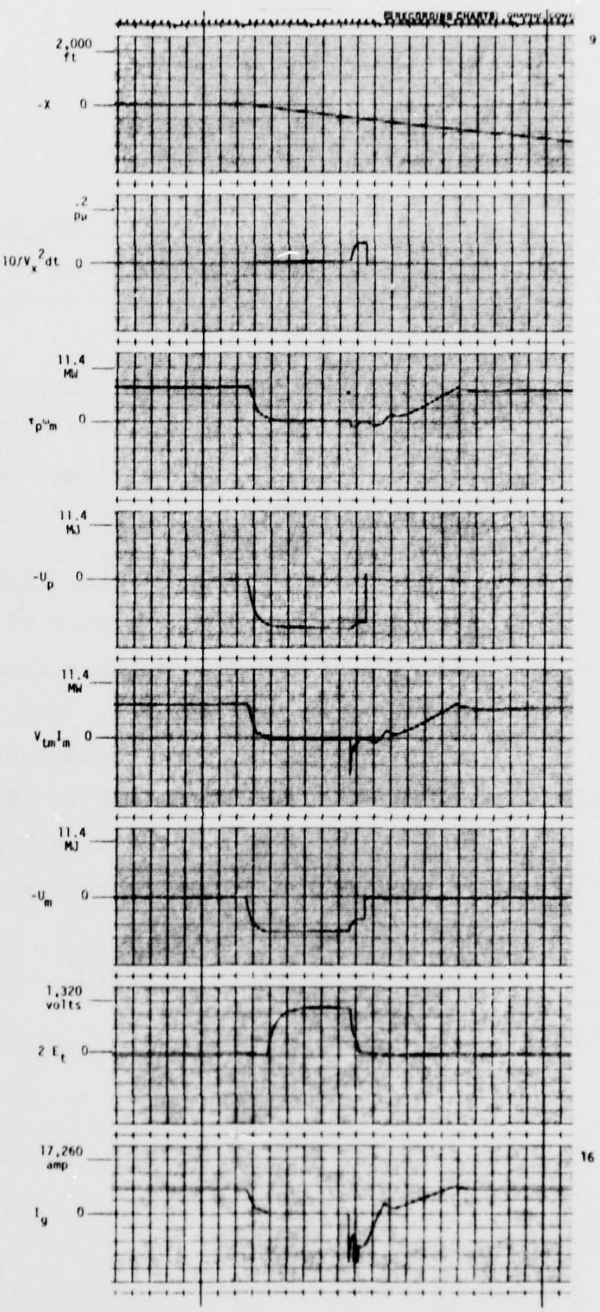
(b)

RECORD 12.4

QUARTER - POWER CONFIGURATION # DYNAMIC BRAKING
REGENERATION FROM FULL AHEAD
L81[6] = $\pm$ 1.000 MAXIMUM TORQUE REFERENCE SLEW RATE $\pm$ 1 PU/SEC
P00[1] = .0888 MINIMUM FUEL RATE 1760 LB/HR



(a)



(b)

RECORD 12.5

QUARTER - POWER CONFIGURATION # DYNAMIC BRAKING
REGENERATION FROM FULL AHEAD
L81[6] = ±.2; MAXIMUM TORQUE REFERENCE SLEW RATE ± .2 PU/SEC
P00[1] = .0402; MINIMUM FUEL RATE = 804 LB/HR

XII. COMPUTER RECORDS (CON'T)

(c) Reacceleration of the Turbine-Generator Set;
Quarter-Power Configuration

We continue to consider the quarter-power configuration of machinery. The regeneration cycle now involves a brake applied to the turbine-generator shaft rather than dynamic braking resistors in the armature circuit.

Record 12.6 is the first of this series to be considered. Before getting to the details, it is necessary to point out that the (a) part of the records have exactly the same traces as previously described in Section 12-b. However, the (b) records include three traces which have not been described before. Channel 9 now shows the braking torque, Channel 10 is the braking power and Channel 11 is the total brake energy. The complete listing of channels for the (b) section of the generator braking records follows.

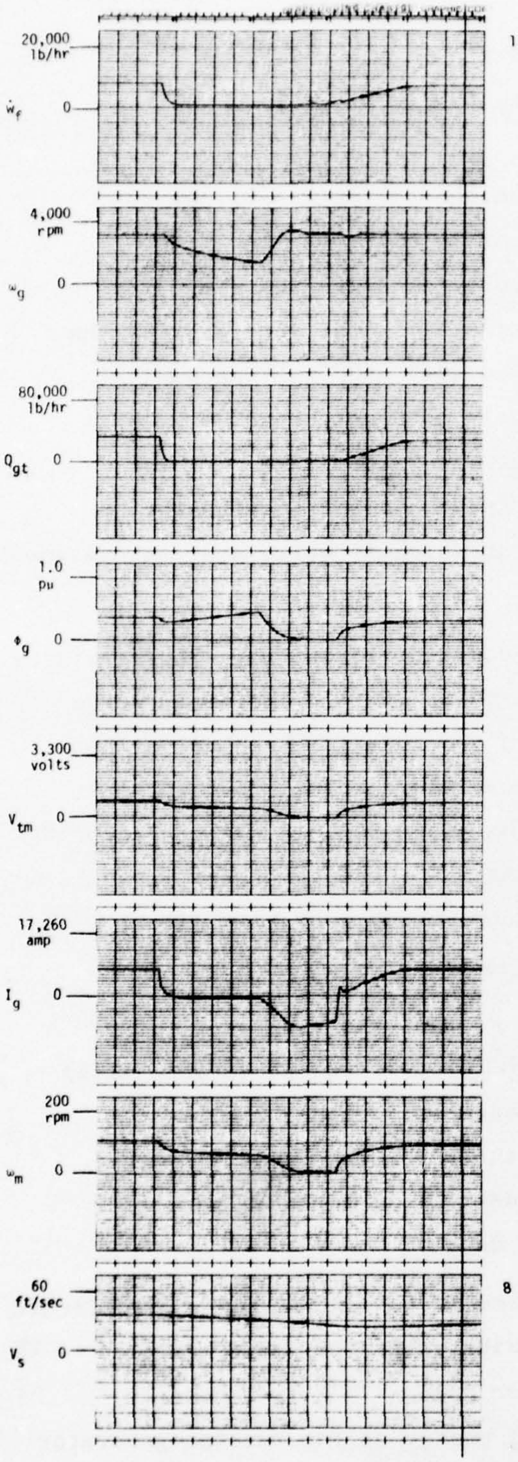
Channel	Variable Symbol	Computer Source	Definition
9	τ_b	T08 [13]	Brake torque
10	P_f	T02 [13]	Brake power
11	U_f	T03 [13]	Brake energy
12	$\tau_p\ \omega_m$	T06 [16]	Propeller power
13	$V_{tm}\ I_m$	T15 [19]	Motor power input
14	U_m	A105 [19]	Motor input energy
15	X	A20 [4]	Ship travel
16	I_g	T07 [7]	Generator current

In the generator braking system the concept is to use the brake to initially slow down the generator in anticipation of the fact that regenerated power from the motor will drive the generator speed back up again. The reason for decelerating the generator is the fact that at the generator speeds involved (say 3600 rpm) mechanical brakes are not yet available that can apply much more than 3000 lb·ft of torque. This is a basic power limitation of the brake. A brake which is designed to hold the generator speed constant during the regeneration cycle has a power requirement which is quite a bit above any brake which has been designed thus far.

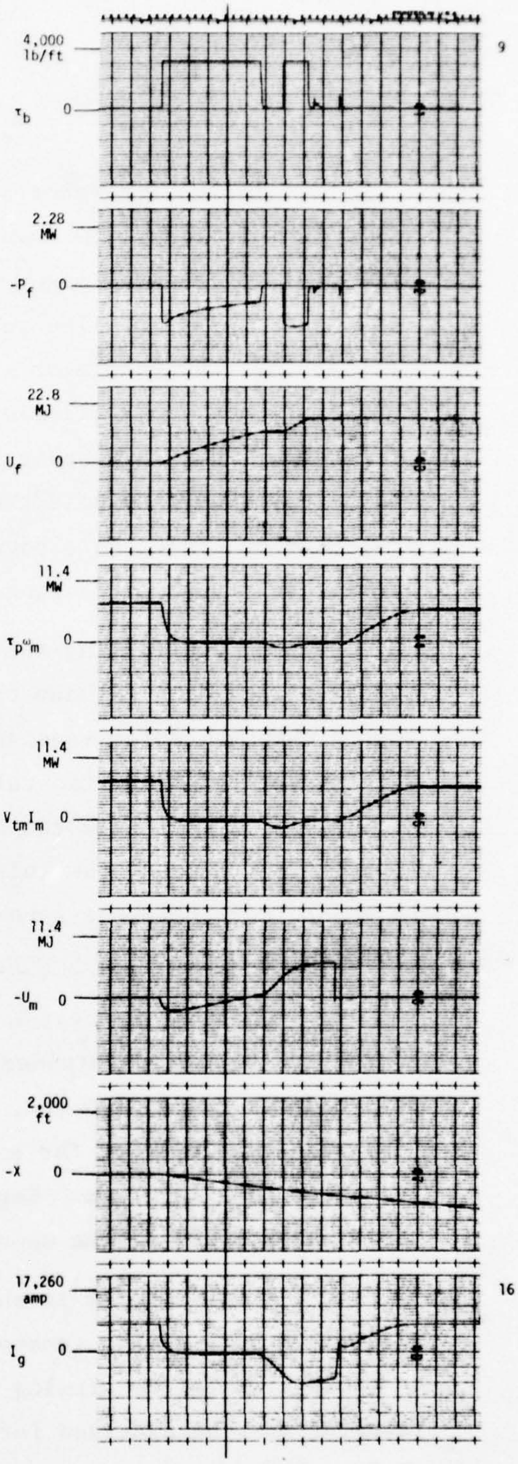
By controlling the brake in a constant torque mode the generator can be slowed down without exceeding its power limit. The power surge occurs when the motor regeneration occurs and this is absorbed by the turbine-generator inertia rather than the brake. It will be seen that at the end of the cycle the brake comes on again to hold the generator speed down. Without the initial deceleration of the generator it would not be possible to hold the generator speed down using a braking effort limited to 3000 lb·ft.

The braking system is adjusted so that the generator speed is reduced to a predetermined lower speed. For this record (Record 12.6) this happens to be 1490 rpm. One can change this value, and records will be shown later on for a case where the minimum generator speed is higher than 1490 rpm. Regarding the details of how this generator speed control works, one should refer to Section XI.

At this point it should be appreciated that without a significant electrical load on the generator the turbine-generator speed control is useless as far as slowing the generator down. This is because a receptor must be provided for the kinetic energy of the turbine-generator shaft. With the generator loaded, the load can serve as the energy receptor. If the generator is unloaded or is only slightly loaded, the brake is the receptor for the energy. In other words, the brake is always available to absorb the turbine-generator kinetic energy no



(a)



(b)

RECORD 12.6

QUARTER - POWER CONFIGURATION # GENERATOR BRAKING
REGENERATION FROM FULL AHEAD
Q27[9] = .4669, P54[9] = .3730; MINIMUM GENERATOR SPEED 1490 RPM
L81[6] = ± 1.0; MAXIMUM TORQUE REFERENCE SLEW RATE ± 1.0 PU/SEC
P65[9] = .1021; FUEL RATE TO REAPPLY REFERENCE 2042 LB/HR
P00[1] = .0402; MINIMUM FUEL RATE 804 LB/HR

matter what the electrical load on the generator may be. Such a receptor is a mandatory requirement because, depending upon initial conditions, the generator may have any arbitrary load within the limits of its rating.

Unfortunately, the situation is even more complicated than simply disposing of the turbine-generator kinetic energy. To see why this is so, we must look at the Record 12.6. When the regeneration cycle commences, two events happen simultaneously. One is to reduce the electrical load on the generator by removing the torque reference signal. The other is to change the generator speed reference to its new lower value.

Three torques are acting upon the turbine-generator inertia at this moment. The gas turbine torque, which as may be seen decays to zero in about a second, tends to increase the speed. The torque caused by the generator load, which is being shed by the motor torque control system, tends to decelerate the generator, and, finally, the torque of the brake. In Record 12.6 from the fact that initial acceleration of the turbine is negative, it is apparent that the net effect of all the torques is to decelerate the generator. This is not so in Record 12.7 where there is an initial increase in turbine speed.

As the turbine-generator rotor slows down, the kinetic energy which it gives up does not all go into the mechanical brake because of the other torques present. During the initial phase of the deceleration, the various torques are very dependent upon the dynamics of the system. However, after two or three seconds the deceleration rate becomes almost constant mainly because of the constant brake torque but also because of an interesting generator control system phenomenon. The torque control system is trying to maintain zero armature current by increasing the generator flux as the generator speed decreases. Observation of the ϕ_g trace shows that the flux increases almost linearily with time as the generator speed drops (also almost linearly with time). The torque control system is basically an integral control system. This type of control

results in zero steady-state error. Consequently if the flux is to change at a constant rate, then there must be a constant error signal driving the integrator which means that there is a motor torque error. Inspection of the I_g trace shows that this is indeed true. The armature current goes right through zero and comes to a constant but small negative value. Since the motor terminal voltage is positive a slight motor regeneration results. The trace $V_{tm} I_m$ shows this power, and the $-U_m$ trace shows the integral of the motor power. From the instant of time when the motor current goes through zero to the time when the regeneration cycle ends, the total regenerated energy is about (11 + 4.5) (11.4)/20 = 8.84 MJ for each motor (see the $-U_m$ trace). Of this energy about 5.5 x 11.4/20 = 3.13 MJ per motor is regenerated because of the inability of the control system to hold the armature current at zero in the face of a changing generator speed.

The total energy regenerted by both motors is 2 x 8.84 = 17.68 MJ. During this same interval of time the brake absorbes about (15-2) (22.8)/20 = 14.82 MJ. Therefore the brake absorbs less energy than that which the motor regenerates. The conservation of energy law requires us to look for other places where the regenerated energy may have gone. The turbine torque is zero during the period of time in question so that is not a factor. The clue is the generator speed. At the moment the generator current I_g goes through zero the turbine speed is seen to be about 13.2 x 4000/20 = 2640 rpm. When the regeneration cycle is completed, the turbine speed is about 16.3 x 4000/20 = 3260 rpm. Can this increase in turbine speed account for the difference between 17.68 MJ and 14.82 MJ or 2.86 MJ? For the quarter-power configuration the value of P71 [2] is .0196 which is one-tenth of the turbine-generator shaft inertia (see Block 2 of computer program). Consequently

$$J_{tg} = .196 \text{ pu}$$

In per unit the initial turbine speed is 13.2/20 and the final speed is 16.3/20. The energy absorbed is

$$\Delta U = \frac{1}{2} J_{tg} (\omega_2{}^2 - \omega_1{}^2) = \frac{1}{2} (.196) \left(\frac{16.3^2 - 13.2^2}{400}\right) = .01986 \text{ pu}$$

The base generator energy is 114 MJ so that in physical units

$$\Delta U = .01986 \times 114 = 2.26 \text{ MJ}$$

which is in satisfactory agreement with the 2.86 MJ for which we are trying to account.

Notice from the ω_g trace that during the motor regeneration portion of the cycle (when ϕ_g is driven to zero) the generator accelerates up to its original speed and even exceeds the original speed. During the acceleration of the generator up to the reference speed, the generator brake must be disabled. However as soon as any overspeed occurs the brake will come on again to hold down the overspeed to the extent possible with constant braking torque. This is what accounts for the second rectangular pulse in the τ_b trace.

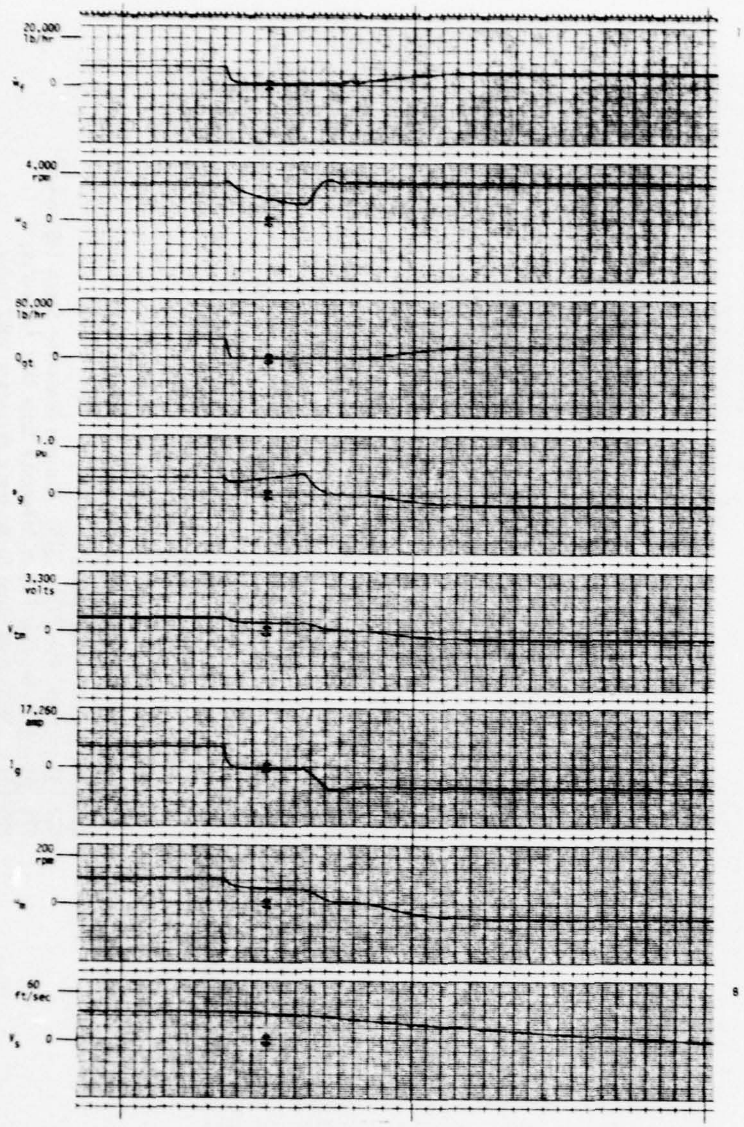
There are two additional small braking pulses shown in the τ_b trace. The first occurs as a result of restoring the generator speed reference to its normal value, and the second occurs when the torque reference is reapplied. In this particular record the original torque reference is reapplied so that we get momentary regeneration as the armature current I_g changes from a negative value to a positive value. This is what causes the second braking pulse.

Record 12.7 is basically the same as 12.6 except the reverse torque reference signal is applied at the termination of the regeneration cycle. As may be observed from the τ_b trace the final braking-torque pulse is gone. This is the result of the fact that no momentary regeneration occurs because the generator current, I_g, remains negative. The ship stopping distance for the particular set of parameters associated with

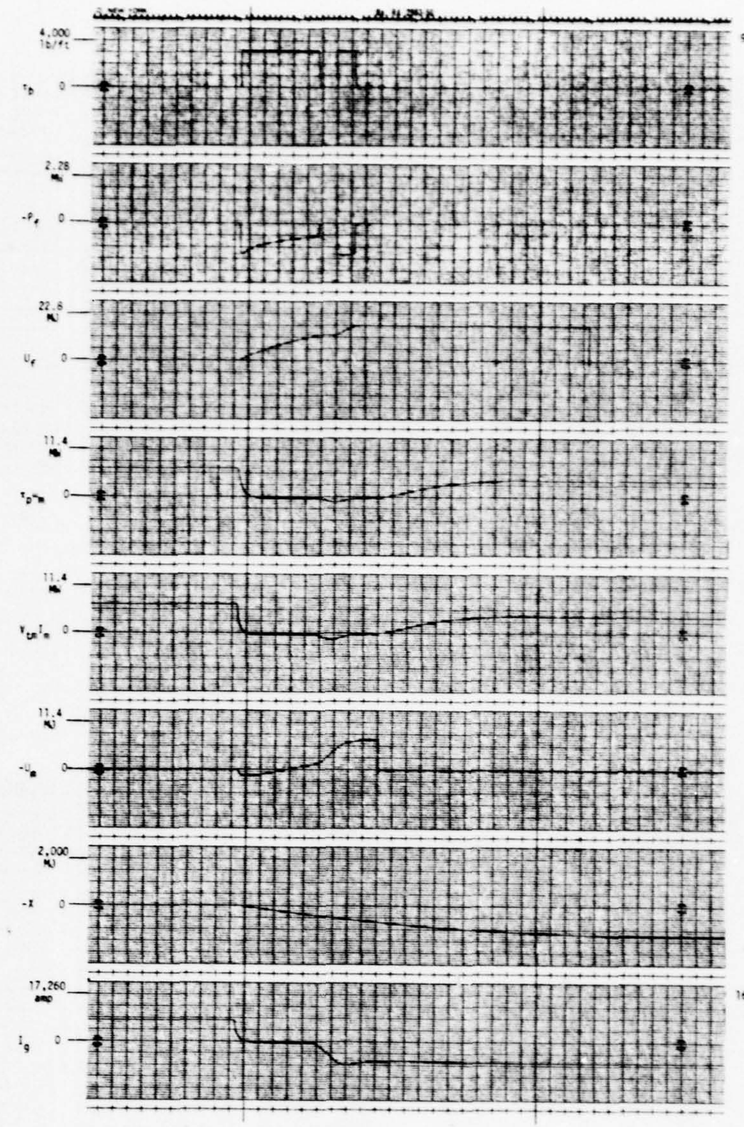
this record is about 1250 ft. It should be emphasized that the stopping distance is dependent upon the exact adjustment of the parameters effecting the dynamics of the control system as well as the initial velocity of the ship and most important of all the final reverse torque reference. Other investigators have gotten lower values, but when actual comparison is made of the mode of operation it invariably results that the propeller was stopped sooner or quicker or the reverse torque reference was greater than assumed here. In other words, the stopping distance is dependent upon the system parameters used, and differences do not necessarily indicate errors in analysis.

The ω_g trace in Record 12.7 shows a increase in speed at the moment the regeneration cycle starts. This does not appear in Record 12.6 for the reason that in Record 12.6 the initial ship speed was slightly higher which resulted in a higher initial motor power. This is clearly evident from the records. In addition the energy absorbed by the motor from the incidence of the regeneration cycle until the armature current, I_g, goes to zero is less in Record 12.7. As a result of this the net torque on the turbine-generator shaft is positive during the initial moments of the cycle, and a slight increase in generator speed results.

The next two records to be considered are Records 12.8 and 12.9. These differ from their counterpart Records 12.6 and 12.7, which we have already discussed, in that the torque reference slew rate has been reduced from $\pm$ 1 pu/sec to $\pm$ .2 pu/sec. Comparing the regeneration-from-full-ahead records (12.6 and 12.8) shows that the total brake energy gets reduced from almost 15 lines in Record 12.6 to about 12.5 lines in Record 12.8. The reason for this is basically that the time to decrease the generator speed is reduce so that the amount of regenerated energy is less. Why this should be can be traced back to the fact that a reduced slew rate of the torque reference supports the generator power longer which augments the mechanical brake. Inspection of either the I_g traces, the $V_{tm} I_m$ traces, or the $-U_m$ traces during the initial decay of the armature current for the two records supports this thesis.



(a)



(b)

Record 12.7

Quarter - Power Configuration # Generator Brake

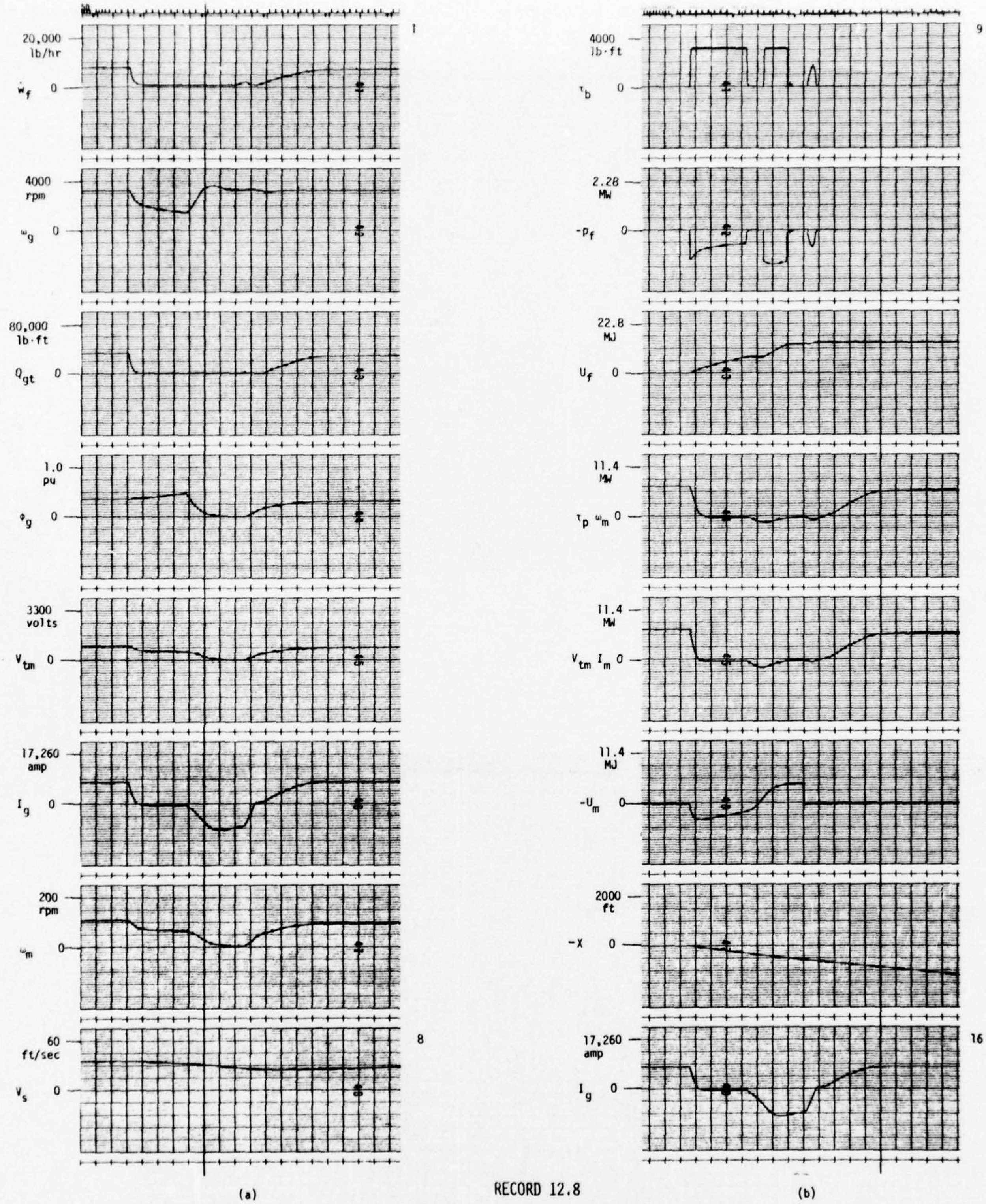
Full Ahead to Full Astern

Q27[9] = .4669, P54 9 = .3730; Minimum Generator Speed 1490 RPM

L81[6] = ± 1.0; Maximum Torque Reference Slew Rate ± 1.0 pu/sec

P65[9] = .1021; Fuel Rate to Reapply Reference 2042 lb/hr

P00[1] = .0402; Minimum Fuel Rate 804 lb/hr



(a) RECORD 12.8 (b)

QUARTER-POWER CONFIGURATION # GENERATOR BRAKING

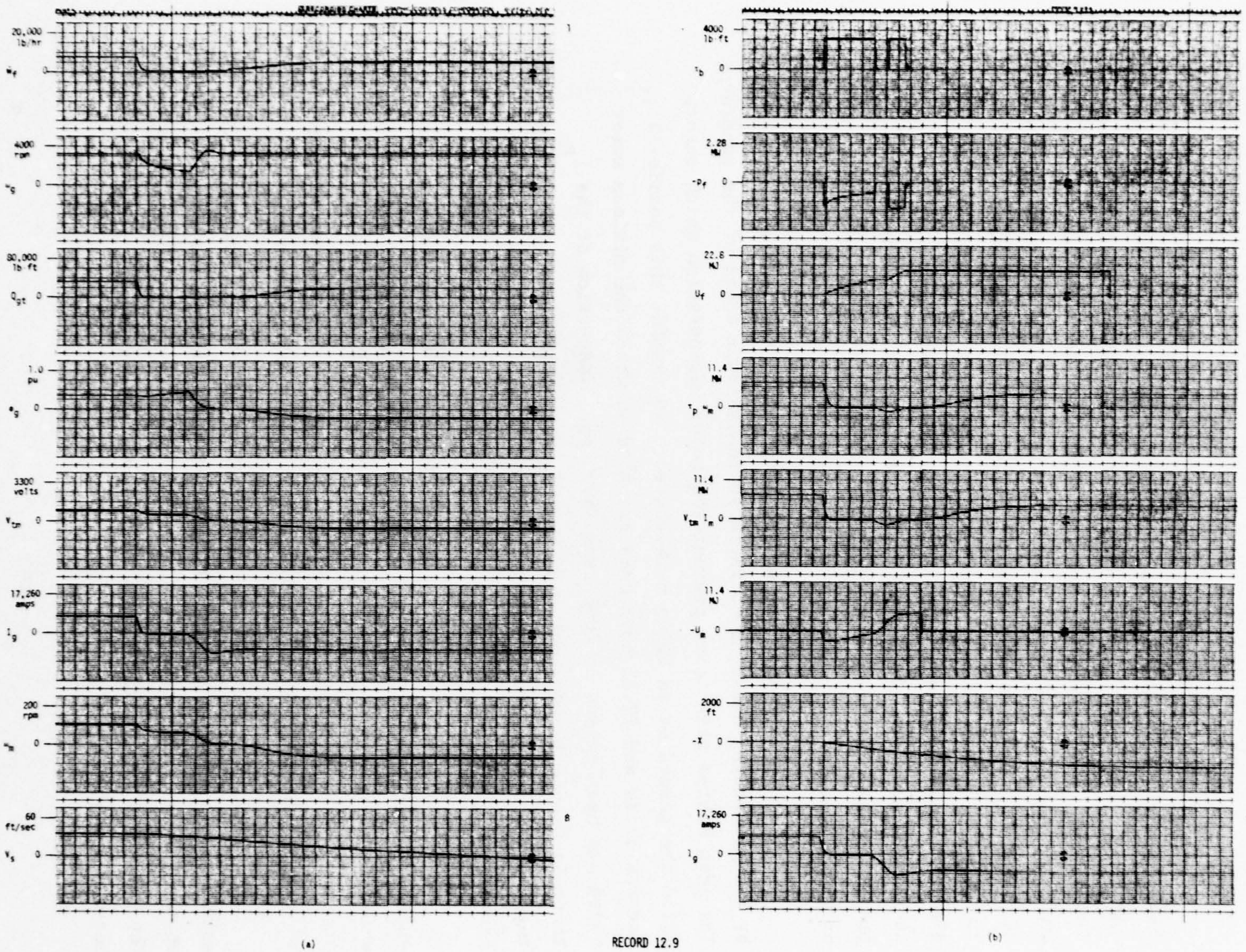
REGENERATION FROM FULL AHEAD

Q27 [9] = .4669, P54 [9] = .3730; MINIMUM GENERATOR SPEED 1490 RPM

L81 [6] = ±.2; MAXIMUM TORQUE REFERENCE SLEW RATE ±.2 PU/SEC

P65 [9] = .1021; FUEL RATE TO RE-APPLY REFERENCE 2042 LB/HR

P00 [1] = .0402; MINIMUM FUEL RATE 804 LB/HR



RECORD 12.9

QUARTER-POWER CONFIGURATION # GENERATOR BRAKING

FULL AHEAD TO FULL ASTERN
Q27 [9] = .4669; P54 [9] = .3730; MINIMUM GENERATOR SPEED 1490 RPM
L81 [6] = ±.2; MAXIMUM TORQUE REFERENCE SLEW RATE ±.2 PU/SEC
P65 [9] = .1021; FUEL RATE TO RE-APPLY REFERENCE 2042 LB/HR
P00 [1] = .0402; MINIMUM FUEL RATE 804 LB/HR

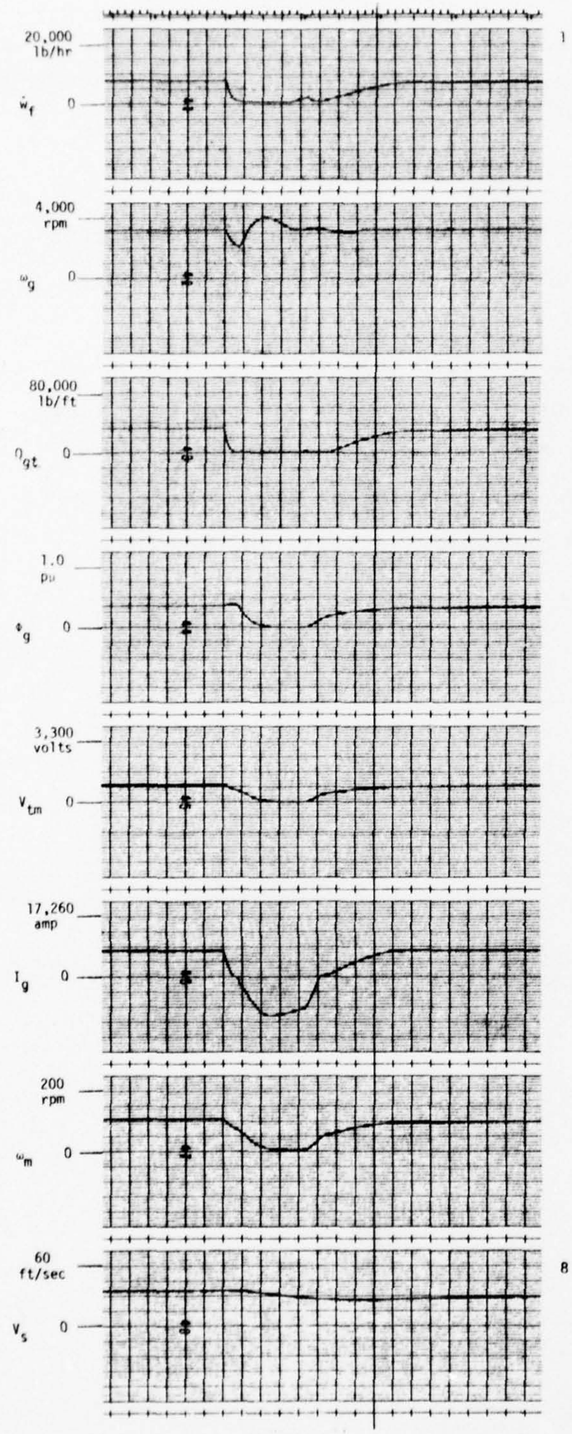
This effect is not a large effect and one cannot expect to significantly reduce the brake power by further slowing down the torque-reference slew rate. In fact another factor comes in which tends to undo the benefit of the reduced slew rate. That is the momentary regeneration which occurs when the torque reference is reapplied. In both Records 12.6 and 12.8 this is responsible for the final braking pulse which in the case of Record 12.8 is much larger because of the reduced slew rate. The additional braking energy caused by this pulse in Record 12.8 is clearly evident. In Record 12.9 this pulse is absent because of the operating mode (full ahead to full astern) so that the brake energy is slightly lower.

It appears that one way to reduce the total energy absorbed by the mechanical brake is to increase the minimum speed of the generator. The idea behind this is to prevent the motor regeneration which occurs while the generator is being decelerated. To examine this possibility, Records 12.10 and 12.11 have been prepared in which the minimum motor speed has been raised to 2042 from 1490 rpm. Inspection of the I_g trace in Record 12.10 shows that, as soon as the generator current goes through zero, the generator flux is driven to zero, and the motor is brought to a halt.

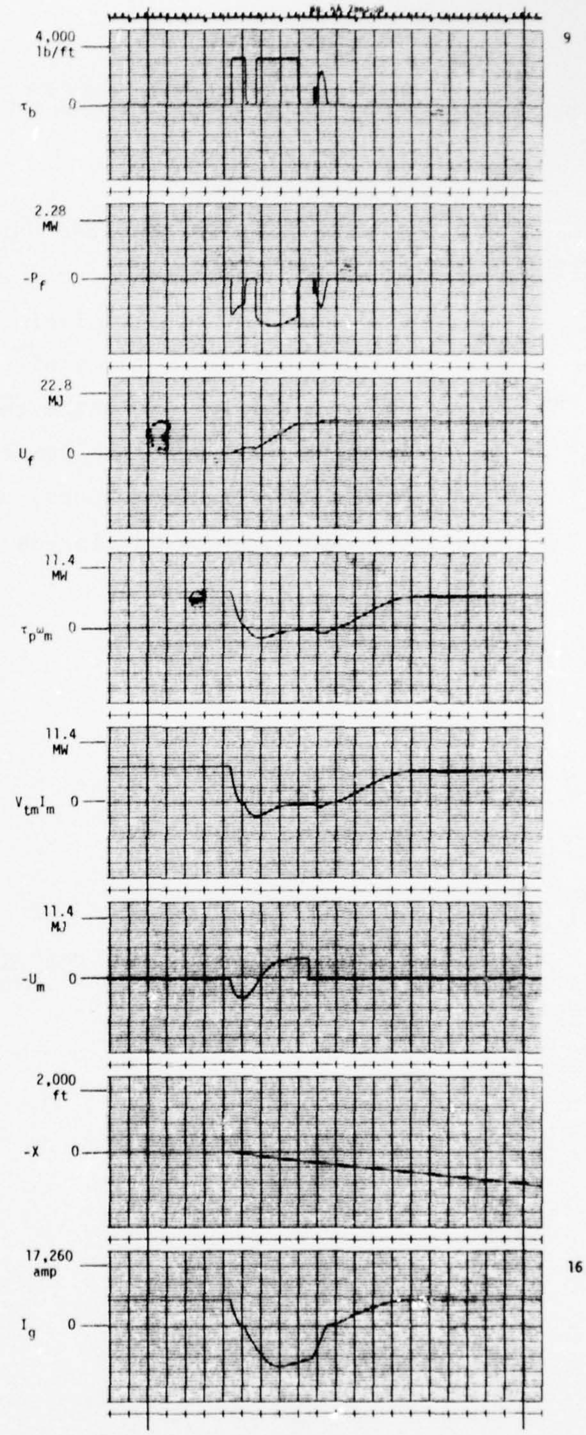
It is true that there is a slight reduction in total brake energy (about 1 part in 12) but there is a gross generator overspeed which is clearly unacceptable. Most of the braking nows occurs in attempting to hold down the generator overspeed. This is unsuccessful because of the 3000 lb· ft limitation of the braking effort.

Record 12.11 shows the performance for the full-ahead to full-astern case. Here we see that the stopping distance is now down to about 1100 ft. This is a result of the fact that the time to slow down the generator is greatly shortened so that reversal of the propeller occurs sooner.

As we conclude our discussion of the quarter-power configuration it should be pointed out that in setting up the computer it is necessary to adjust the minimum fuel flow rate to a value which will give zero turbine torque at the minimum speed. In our case this was about 804 lb/hr as indicated in the record captions. If excessive minimum fuel flow is used, it may not be possible for the brake to slow the generator down to the minimum speed, and the brake must absorb the power which the turbine is producing as its minimum fuel flow setting (which is too high).



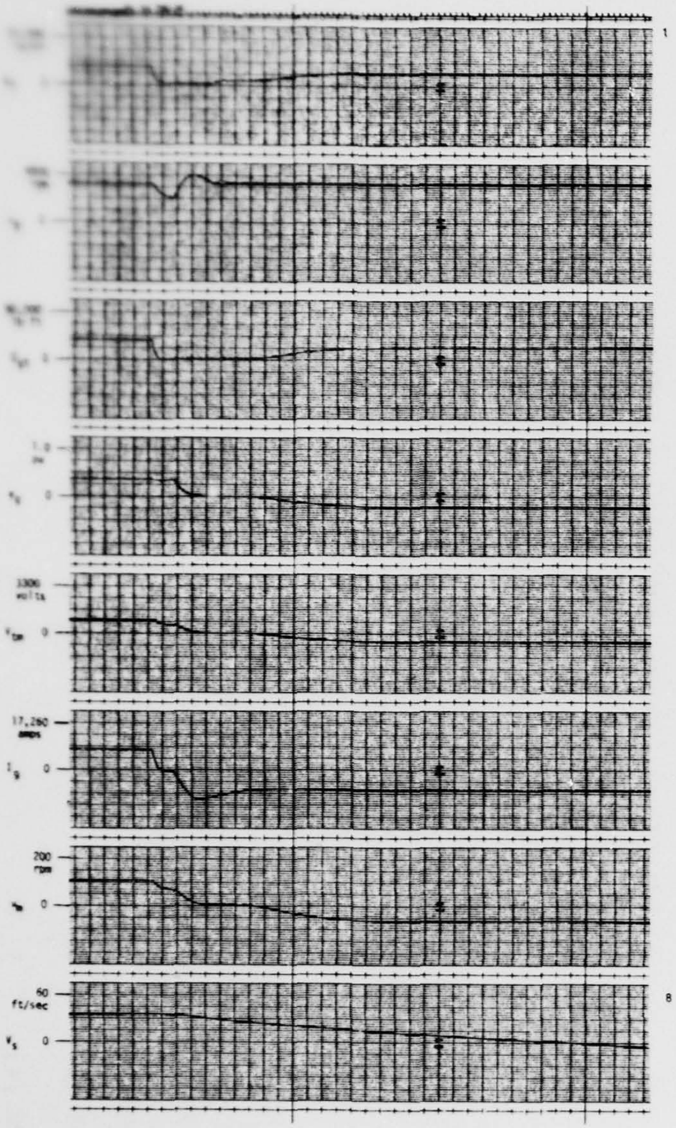
(a)



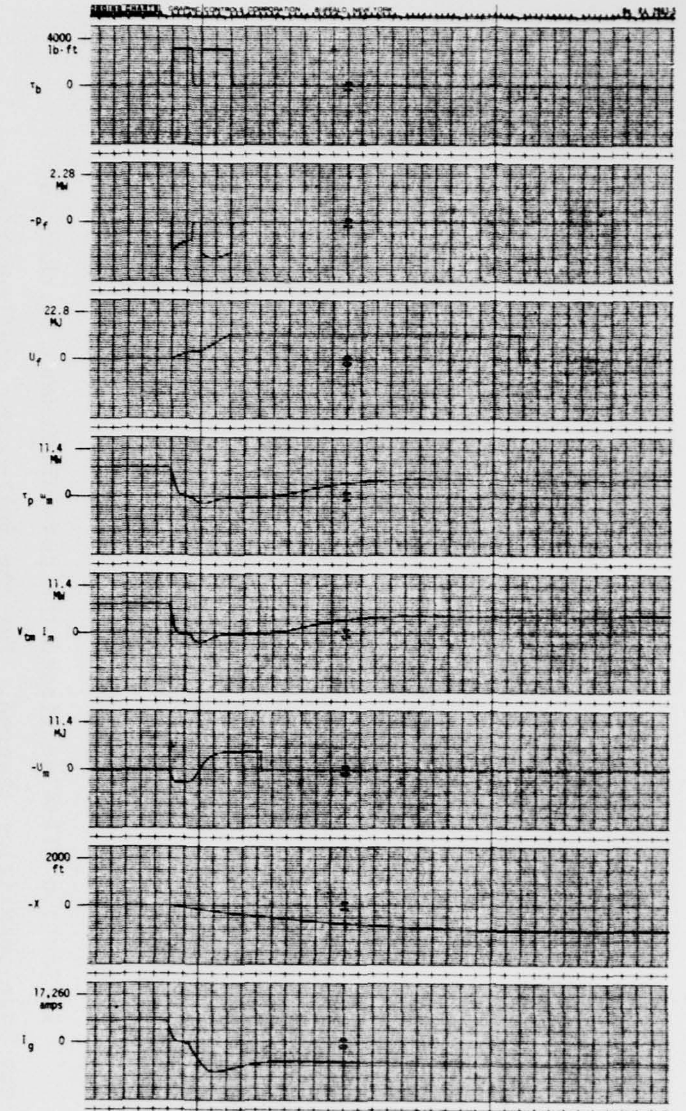
(b)

RECORD 12.10

QUARTER - POWER CONFIGURATION # GENERATOR BRAKING
REGENERATION FROM FULL AHEAD
Q27[9] = .317, P54[9] = .5250; MINIMUM TURBINE SPEED INCREASED TO 2100 RPM
L31[6] = ± .2; MAXIMUM TORQUE SLEW RATE ± .2 PU/SEC
P65[9] = .1021; FUEL FLOW RATE TO REAPPLY REFERENCE 2042 LB/HR
P00[1] - .0402; MINIMUM FUEL FLOW RATE 804 LB/HR



(a)



(b)

RECORD 12.11

QUARTER-POWER CONFIGURATION # GENERATOR BRAKING

FULL AHEAD TO FULL ASTERN
Q27 [9] = .317, P54 [9] = .5250; INCREASE TURBINE MINIMUM SPEED TO 2100 RPM
L81 [6] = ±.2; MAXIMUM TORQUE SLEW RATE .2 PU/SEC
P65 [9] = .0919; FUEL FLOW RATE TO RE-APPLY REFERENCE 1838 LB/HR
P00 [1] = .0402; MINIMUM FUEL FLOW RATE 804 LB/HR

XII. COMPUTER RECORDS (CON'T)

(d) Dynamic Braking Full-Power Configuration

We now consider the full-power configuration where we have two paralleled turbine-generators driving a single motor. This configuration has been described in detail in Section VIII. For all the records which will be discussed related to this configuration, the per unit base quantities are for Base Set I: Full-Power Configuration, Var I. Section VIII defines these base quantities.

In Section XII-a we listed the pots which must be changed when the base quantities changed. For the full-power configuration these pots must have the following values.

P13 [1]	= .267	P49 [17]	= .2481
P71 [2]	= .0523	P79 [17]	= .1428
P95 [2]	= .0069	P104 [17]	= .0896
Q12 [2]	= .0000	P109 [17]	= .0551
P11 [3]	= .378	P55 [21]	= .1343
P38 [3]	= .0185	Q27 [21]	= .0365
P107 [5]	= .3890	Q29 [21]	= .0698
P29 [16]	= .3890	Q09 [21]	= .1431
P116 [17]	= .0254	Q22 [21]	= .0562
P19 [17]	= .6151	Q24 [21]	= 1.000

When the ship is in the steady-state, full-ahead condition the following values of the various variables obtain:

Component	Variable	Value in pu	Physical Value
A91 [2]	V_{tg}	.5771	1910 volts
A20 [4]	$V_s/60$	.2428	V_s = 56.6 ft/sec
A10 [3]	ω_m	.8571	171.3 rpm

Component	Variable	Value in pu	Physical Value
A42 [3]	ϕ_m	.6614	
A13 [3]	τ_m	.389	1.178×10^6 lb·ft
A94 [7]	I_m	.588	15180 amp
A43 [3]	$-E_m$	-.5666	1870 volts
A98 [2]	$-E_g$	-.5814	1915 volts
A16 [4]	$D_s/10^6$	.5761	$D_s = .576\times10^6$ lbs
A24 [5]	$\sin\theta$	.6321	
F52 [5]	$5\ C_Q$	.1387	
F32 [5]	C_T	.1071	
A33 [5]	$-T/(2\times1.83\times10^6)$	-.0786	$T = .2875\times10^6$ lbs
A103 [5]	$-5Q/(2\times29.3\times10^6)$	-.1005	$Q = 1.176\times10^6$ lb·ft
A00 [1]	$\dot{w}_f/(2\times10^4)$	.3977	$\dot{w}_f = 7930$ lb/hr
A66 [1]	$Q_{gt}/(2\times10^5)$	.1603	$Q_{gt} = .321\times10^5$ lb·ft
P13 [1]	$\tau_t/10$	.0427	$\tau_t = .321\times10^5$ lb·ft
A68 [2]	$-\tau_g$	-.427	$.3205\times10^5$ lb·ft
A70 [2]	ω_g	.8015	3210 rpm
P22 [14]	Torque ref. level	.3898	
Q22 [14]	Torque ref. level	.3898	

The records for the dynamic braking case include Records 12.12, 12.13 and 12.14. Traces on these records are identified in exactly the same way as for the quarter-power dynamic braking records and need no further explanation.

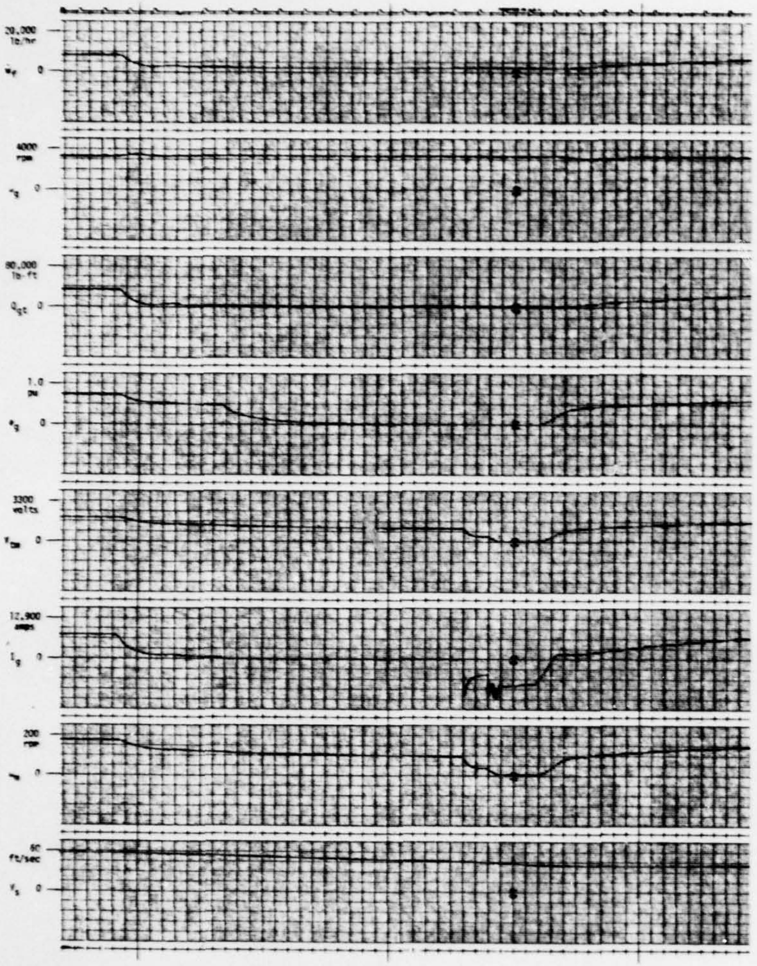
Record 12.12 shows the regenerative cycle from full-speed ahead and has been taken at a high chart speed for the purpose of showing the detail of the dynamic braking current pulses.

When dynamic braking is used, the minimum fuel flow must be increased to prevent a sudden reduction of the generator speed when the torque reference is reapplied. For this reason, for the dynamic braking records, the minimum fuel flow is set at 1760 lb/hr as the captions show.

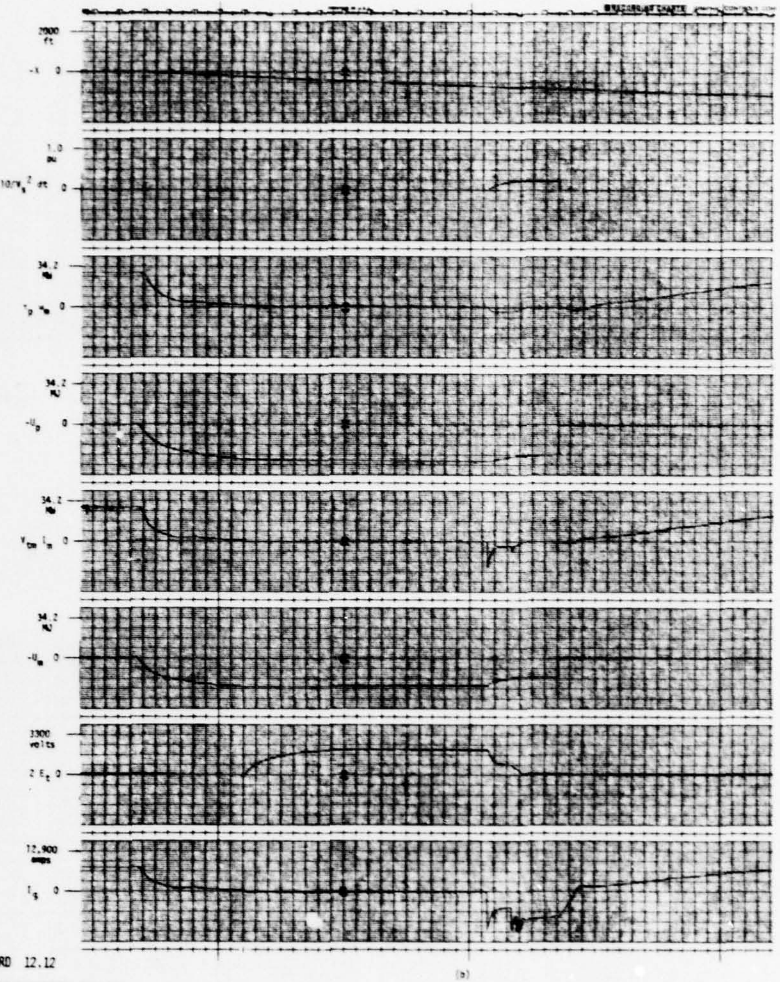
In Record 12.13 the reference torque slew rate is set at 1 pu/sec. This results in a modest increase in generator speed when the generator current, I_g, is initially reduced to zero. As explained in connection with the quarter-power configuration, this occurs because of the delay in getting the fuel valve closed. The rapid torque reference slew rate has the very definite advantage of reducing the regeneration which occurs when the initial torque reference is reapplied as Record 12.12 shows.

In Record 12.13 the torque reference slew rate has been reduced to .2 pu/sec. The regeneration cycle from full-ahead case is shown, and as might be expected there is a large increase in turbine speed when the full-ahead torque reference is reapplied. Not only this, the traces of $-U_m$ and $-U_p$ go off scale because of the initial delay in unloading the generator. This of course does not occur in Record 12.12.

The full-ahead to full-astern case is shown in Record 12.14. In this run the torque reference slew rate has been returned to 1 pu/sec. The total ship travel before zero velocity is achieved is 1440 ft. As previously mentioned this is not an absolute figure and could be reduced by commanding a higher reverse torque.



(a)

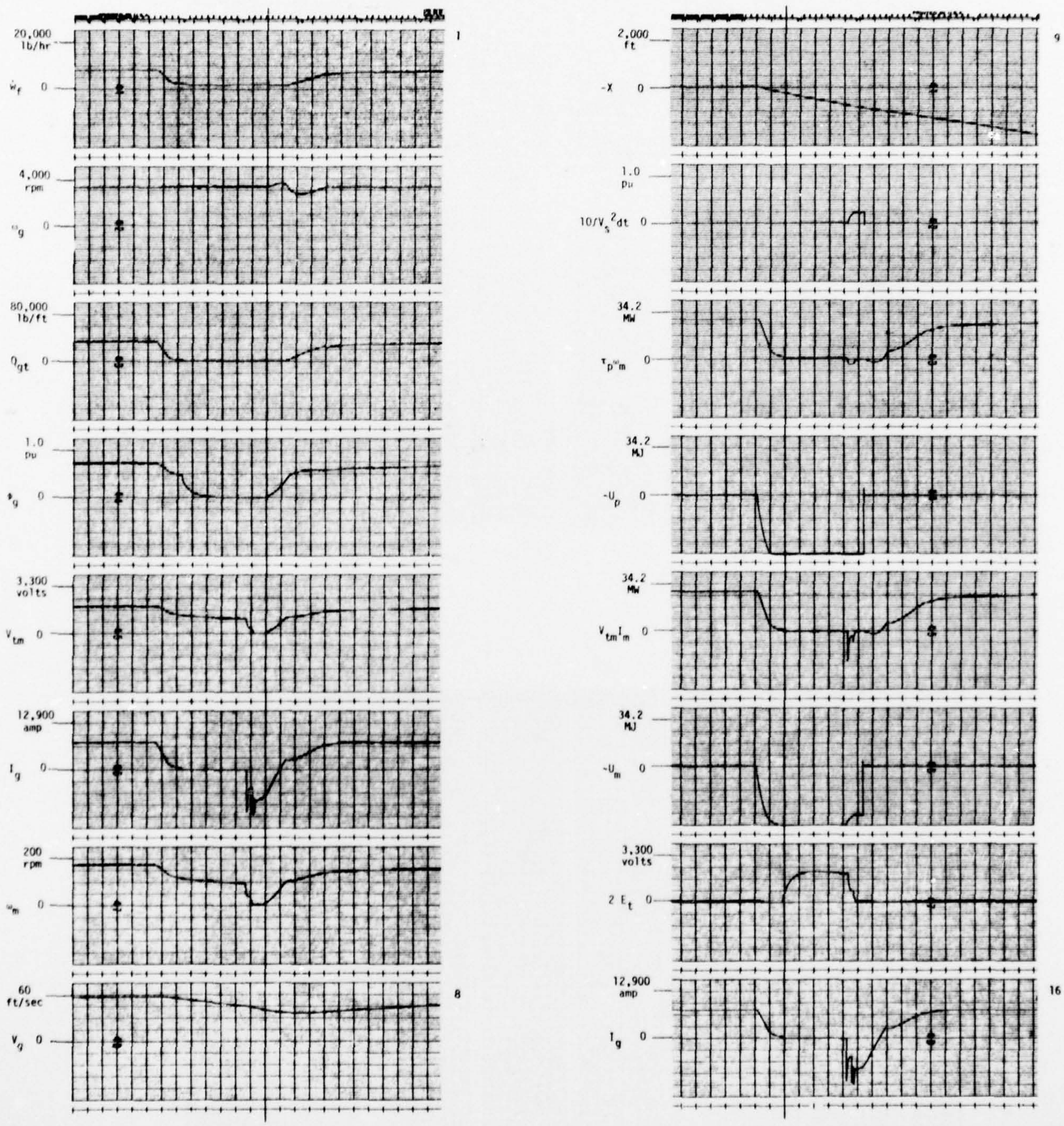


(b)

RECORD 12.12

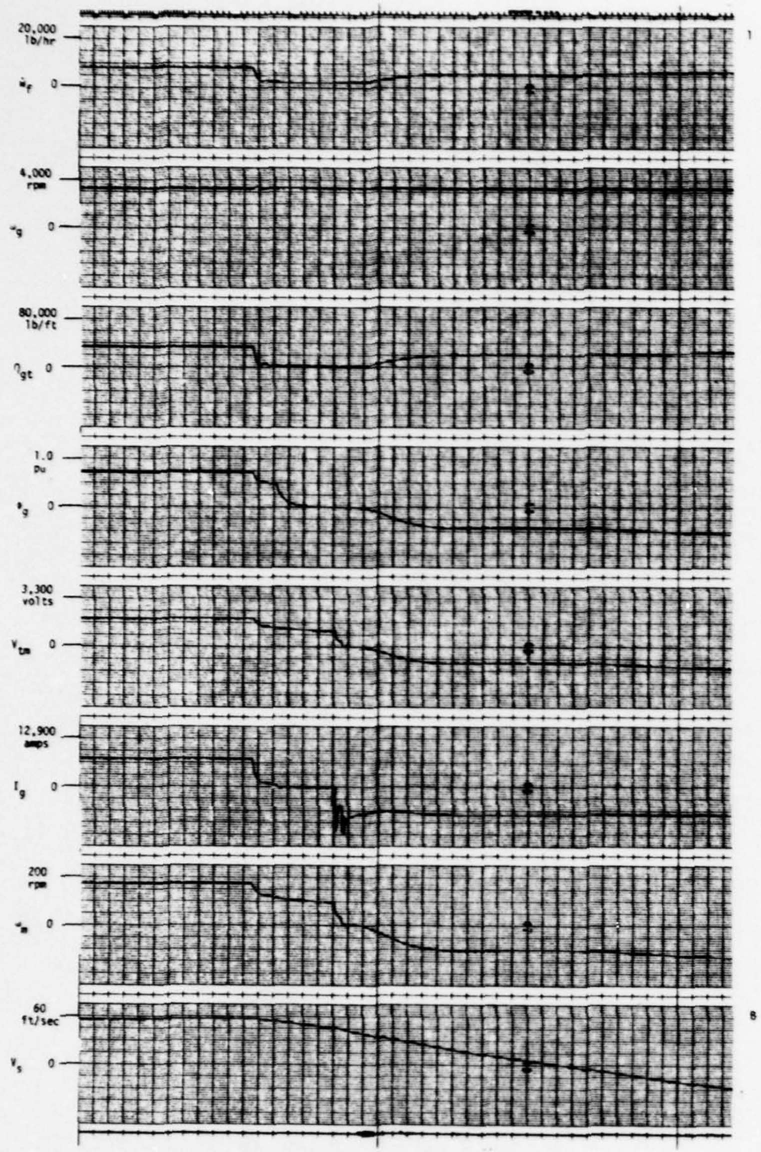
FULL-POWER CONFIGURATION # DYNAMIC BRAKING

REGENERATIVE CYCLE FROM FULL AHEAD
L81 [6] = ±1.0; MAXIMUM TORQUE REFERENCE SLEW RATE 1.0 PU/SEC
P00 [1] = .0880; MINIMUM FUEL FLOW RATE 1760 LB/HR

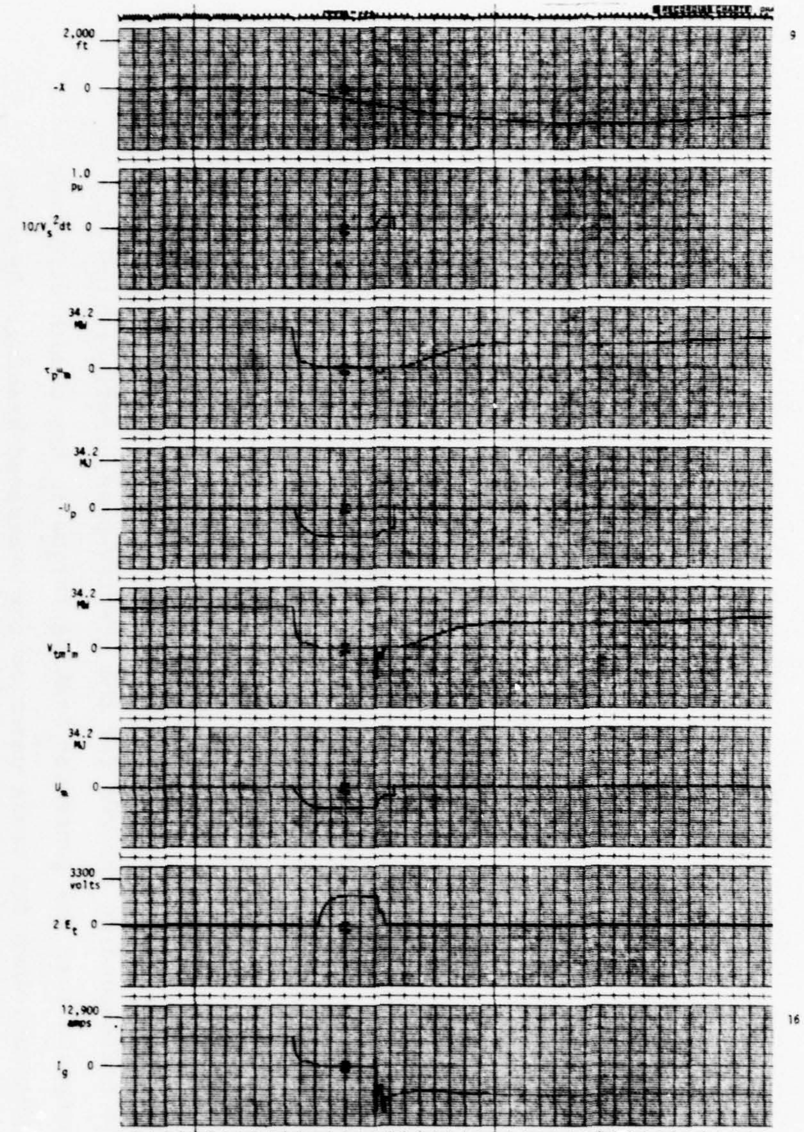


RECORD 12.13

FULL - POWER CONFIGURATION # DYNAMIC BRAKING
REGENERATION CYCLE FROM FULL AHEAD
L81[6] = ±.20; TORQUE SLEW RATE ± .2 PU/SEC
P00[1] = .0880; IDLE FUEL FLOW 1760 LB/HR



(a)



(b)

RECORD 12.14

FULL - POWER CONFIGURATION # DYNAMIC BRAKING
FULL AHEAD TO FULL ASTERN
L81[6] = ± 1.0; MAXIMUM TORQUE REFERENCE SLEW RATE ± 1.0 PU/SEC
P00[1] = .0880; MINIMUM FUEL FLOW RATE 1760 LB/HR

XII. COMPUTER RECORDS (CON'T)

(e) Reacceleration of the Turbine-Generator Set; Full-Power Configuration

We now consider the system performance using generator braking to prevent overspeed but with the full-power configuration. The identification of the traces has been covered in relation to the quarter-power configuration, and will not be discussed here.

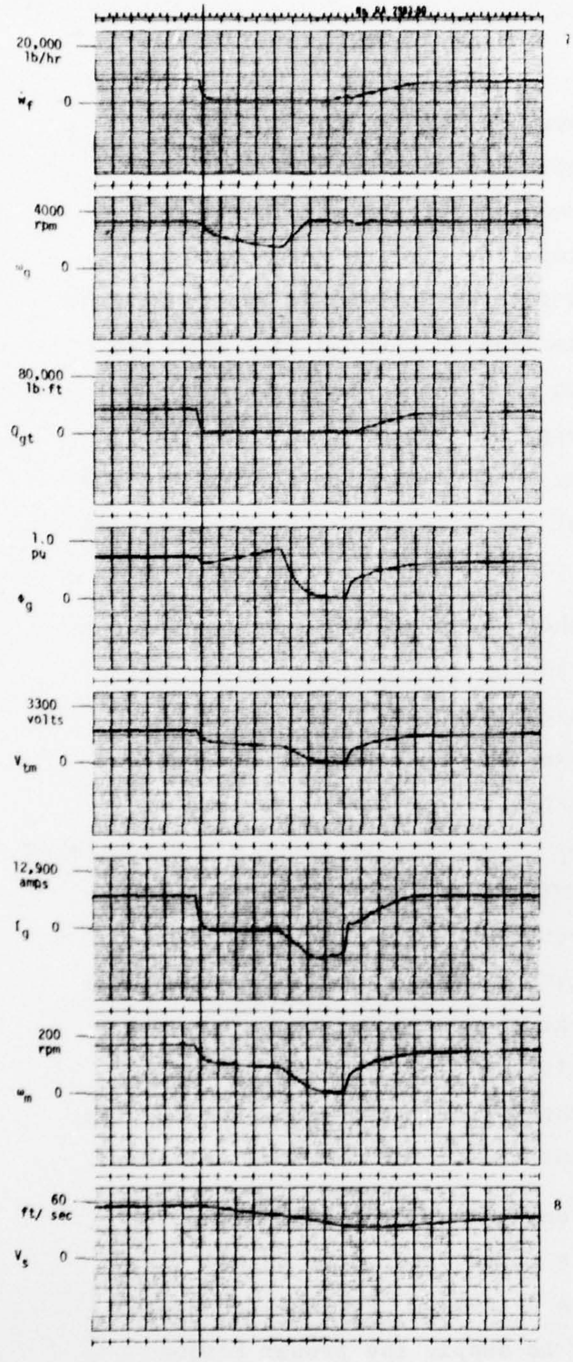
Record 12.15 shows the results with the torque reference slew rate set at $\pm 1.$ pu/sec. The results are not greatly different from the corresponding records for the quarter-power configuration with the exception that the generator braking torque τ_b has a much different appearance when the brake comes on for overspeed braking. Here we see the brake being applied and released in rapid succession — a type of operation which was completely unknown heretofore. The brake is operated by the speed error signal. Therefore, if we see the brake rapidly switching on and off it must be accompanied by an alternately positive and negative error signal. The simple explanation is that when the brake comes on there is enough braking effort to more than reduce the speed error to zero. Indeed, the error actually goes negative so the brake goes off. However, the motor is still regenerating energy so that the generator speeds up again and the process is repeated until the motor regeneration ceases. This kind of operation did not occur with quarter-power configuration because the brake is absorbing the regenerated energy from two motors so that the braking effort is not sufficient to even cause the speed error to go negative. As a result the brake comes on and stays on. This is a good example of a so-called bang-bang system.

In relation to the quarter-power configuration we found that if one reduced the torque reference slewing rate that the energy which the brake must absorb is reduced for the simple reason that more of the energy goes out the propeller via the motor rather than into the brake. This is also true for the full-power configuration. Record 12.16 shows the regneration cycle from full-ahead case when the torque reference slew rate is reduced to .2 pu/sec. Comparison with Record 12.15 shows that the braking energy is reduced from about 15.7 lines to 11 lines. The brake energy now amounts to 11 x 17.08/20 = 9.38 MJ. This is less energy than for any of the quarter-power configuration cases which were run.

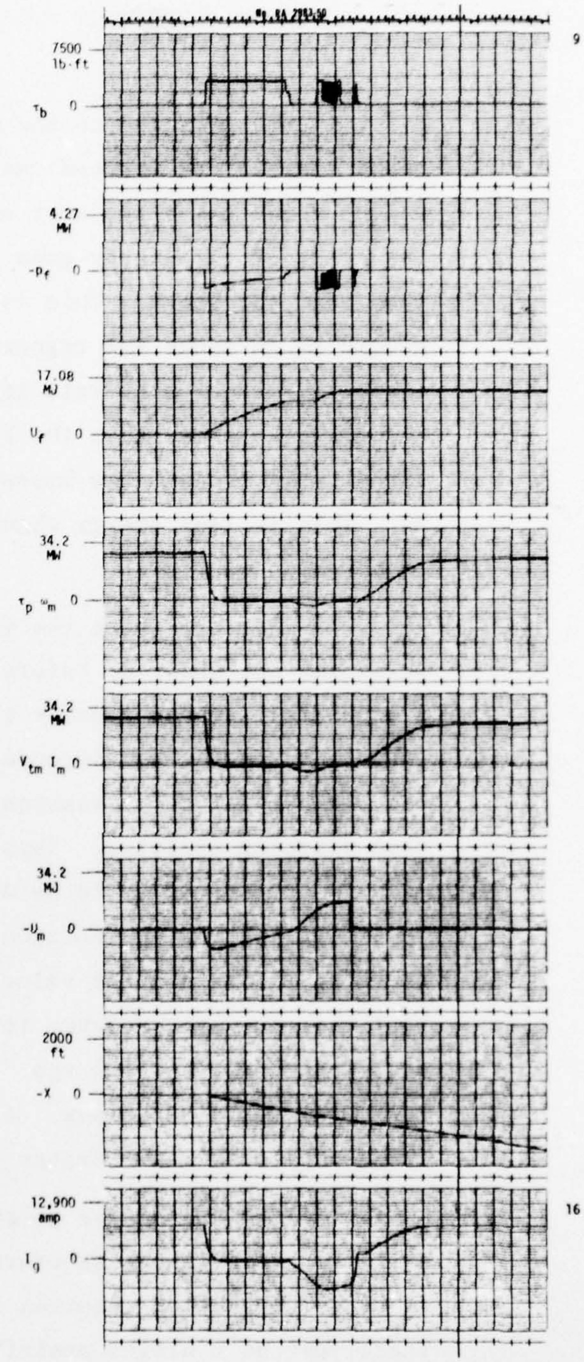
For this case the waveforms show an interesting new constraint which had not shown up before. Inspection of the ω_g trace shows that the generator speed reaches its controlled lower speed and remains there for about seven seconds. Meanwhile the generator current which had been negative for reasons already explained goes through zero and then slightly positive. This strange behavior results because the generator flux is not permitted to be driven to zero unless the motor speed is less than 100 rpm in addition to the requirement that the generator speed be at its minimum value. Inspection of the ω_g and ω_m traces shows that the generator reaches its lower controlled speed long before the motor speed reaches 100 rpm. As a result the cycle is held up while the motor speed decreases. After the motor speed passes through 100 rpm, the generator flux is driven to zero, and the cycle continues as normal.

The reason the generator current goes slightly positive is that, although the generator speed is fixed, the motor speed is decreasing which requires the flux to decrease. For this to happen there must be a slight positive current to supply the proper torque error to the generator field-control integrator.

Next we come to the full-ahead to full-astern records which are shown in Records 12.17 and 12.18. Record 12.17 shows that the ship is brought to a stop in about 1480 ft. The torque reference slew rate



(a)



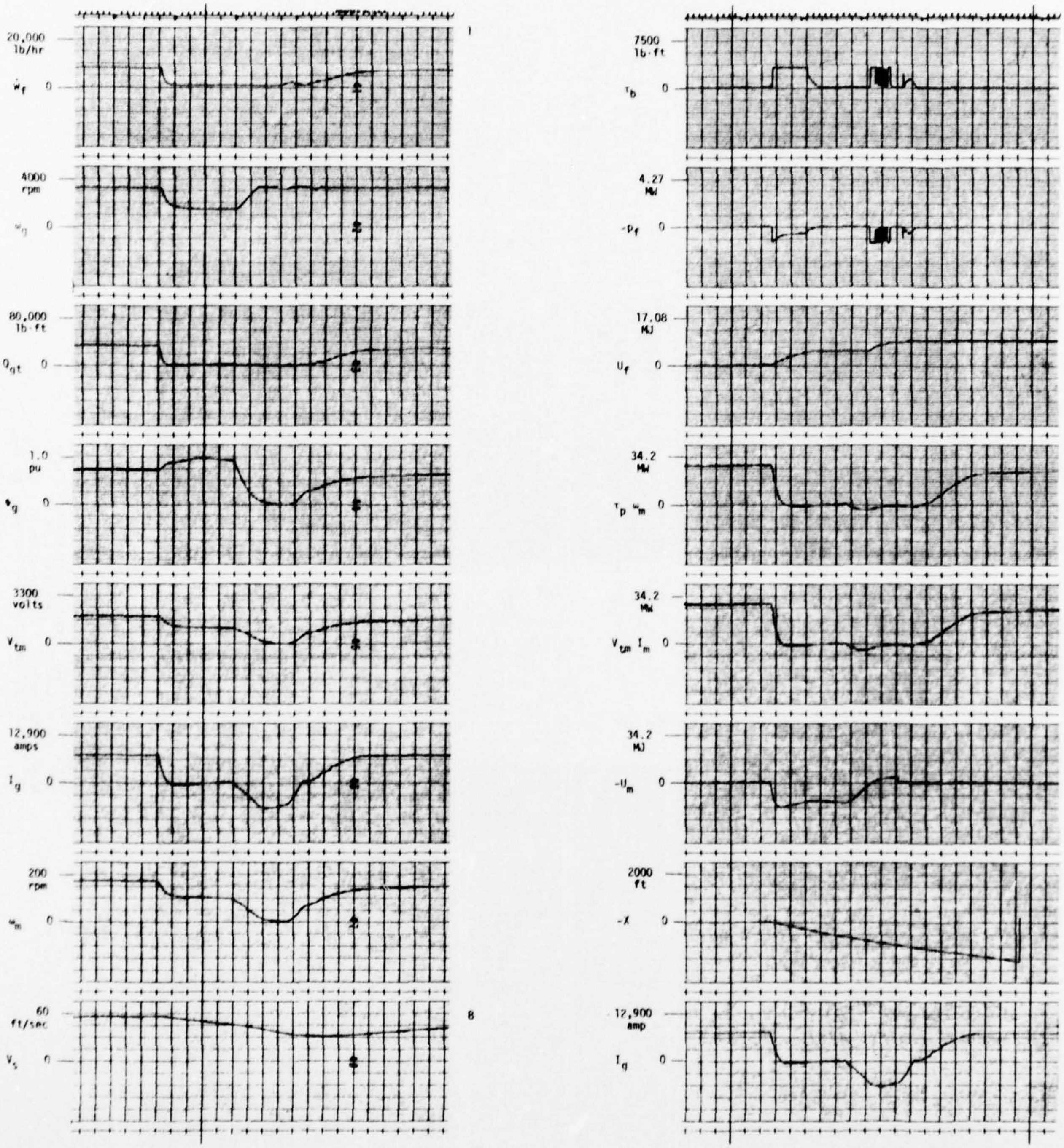
(b)

RECORD 12.15

FULL-POWER CONFIGURATION # GENERATOR BRAKING

REGENERATION CYCLE FROM FULL AHEAD

L81 [6] = $\pm$1.00; MAXIMUM TORQUE SLEW RATE LIMIT $\pm$1.0 PU/SEC
P00 [1] = .0402; MINIMUM FUEL FLOW RATE 804 LB/HR
Q27 [9] = .4669, P54 [9] = .3730; MINIMUM GENERATOR SPEED 1490 RPM
P65 [9] = .1021; FUEL FLOW RATE TO RE-APPLY REFERENCE 2042 LB/HR

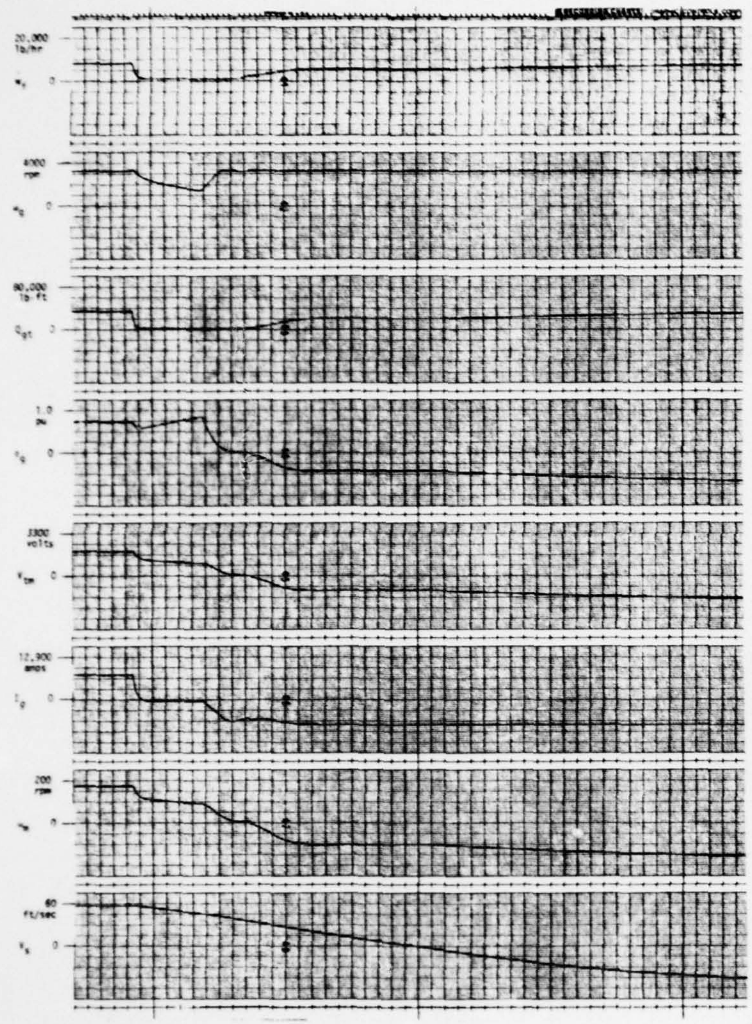


(a) RECORD 12.16 (b)

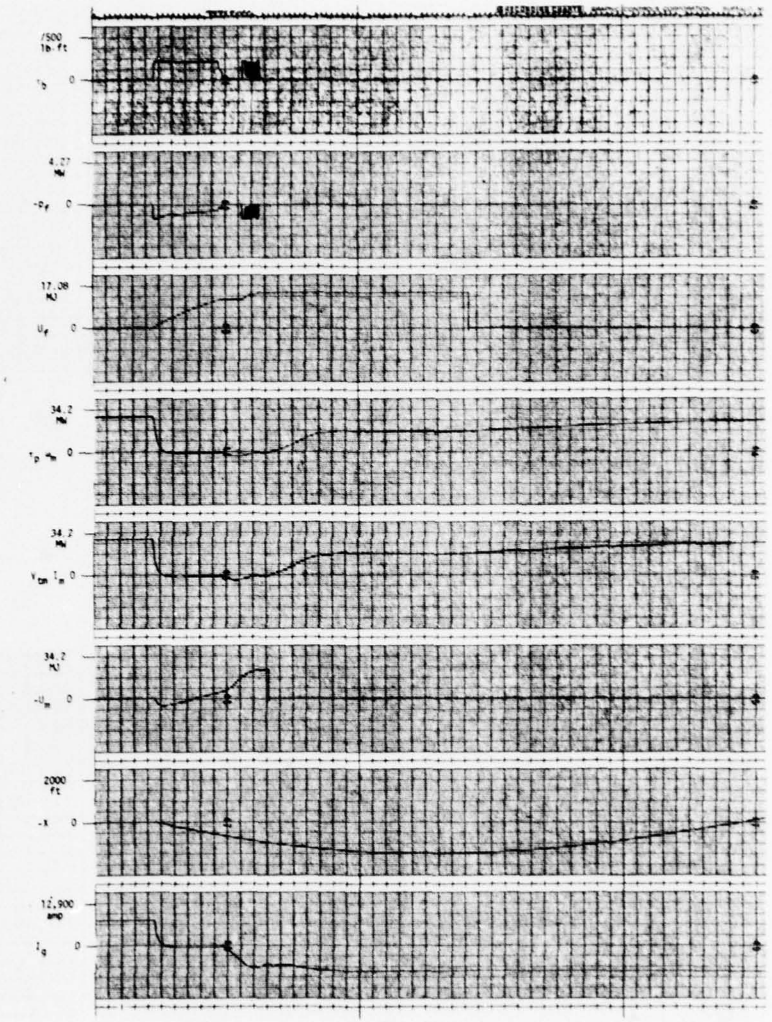
Full-Power Configuration # Generator Braking

Regeneration Cycle from Full Ahead

L81 [6] = ±.200; Maximum Torque Slew Rate ±.2 pu/sec
P00 [1] = .0402; Minimum Fuel Flow Rate 804 lb/hr
Q27 [9] = .4669, P54 [9] = .3730; Minimum Generator Speed 1490 rpm
P65 [9] = 1021; Fuel Flow Rate to Re-Apply Reference 2042 lb/hr



(a)

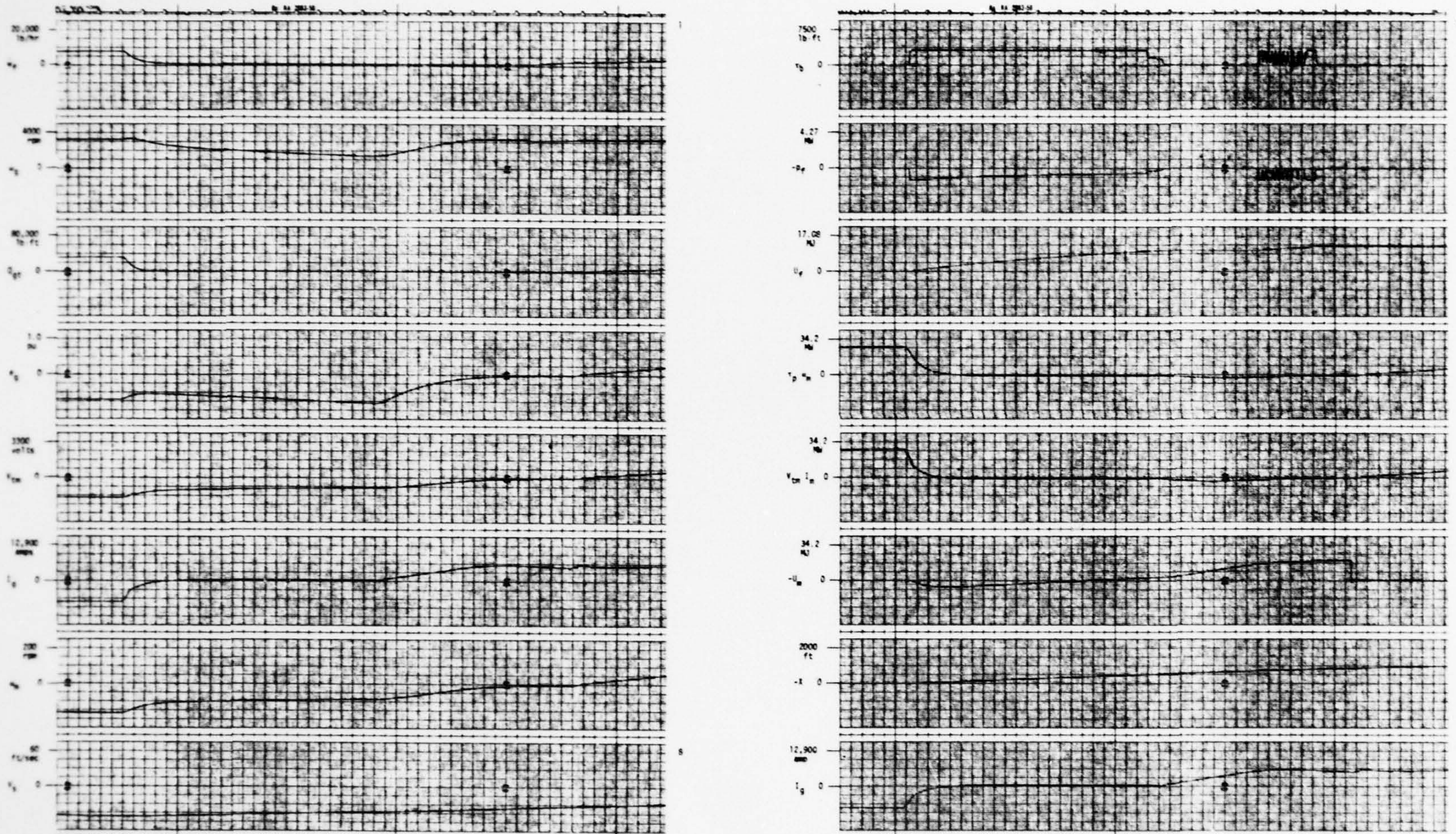


(b)

RECORD 12.17

Full-Power Configuration # Generator Braking

Full Ahead to Full Astern
L81 [6] = ±1.00; Maximum Torque Reference Slew Rate ±1.0 pu/sec
P00 [1] = .0408; Minimum Fuel Flow Rate 804 lb/hr
Q27 [9] = .4669, P54 [9] = .3730; Minimum Generator Speed 1490 rpm
P65 [9] = .1021; Fuel Flow Rate To Re-Apply Reference 2042 lb/hr



(a)

(b)

RECORD 12.18

FULL-POWER CONFIGURATION # GENERATOR BRAKING

SEMI-FULL ASTERN TO FULL AHEAD
L81 [6] = ±1.0; MAXIMUM TORQUE REFERENCE SLEW RATE 1.0 PU/SEC
P00 [1] = .0402; MINIMUM FUEL FLOW RATE 804 LB/HR
Q27 [9] = .4669, P54 [9] = .3730; MINIMUM GENERATOR SPEED 1490 RPM
P65 [9] = .1021; FUEL RATE TO RE-APPLY REFERENCE 2042 LB/HR

has been increased back up to 1 pu/sec so that the brake energy required for the maneuver is 17 x 17.08/20 = 14.5 MJ. Record 12.18 shows a performance record when the initial ship speed is less than full astern but the torque reference has been switched to the full ahead value. This record is run at high speed so that one can easily observe the detail of the braking torque pulses. The initial speed at which the torque reference change occurs greatly influences the brake energy since the propeller power and the kinetic energy of the motor-propeller inertia both enter into the picture. In this case the brake energy is reduced to 14.3 x 17.08/20 = 12.2 MJ.

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SEGMAG MACHINES FOR MARINE ELECTRICAL PROPULSION SYSTEMS. APPEN--ETC(U)
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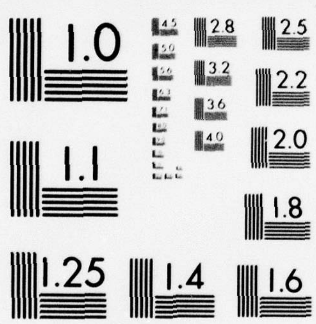


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

XIII. SUMMARY AND CONCLUSIONS

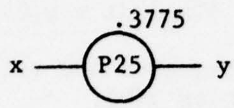
In this report the problem of controlling an electric ship drive is considered. The electric machines are the usual Ward-Leonard dc generator and motor combination. The generator prime mover is the General Electric LM 2500 gas turbine. The major control problem is that of providing a means to accommodate regeneration of energy from the motor, which occurs with certain maneuvers, in a manner that will not cause excessive overspeeding of the gas turbine.

Various technical aspects of the problem are considered and a number of means for overcoming the numerous difficulties are examined. Two reasonable control systems have been found to be practical. One involves a mechanical brake on the gas turbine shaft, and the other utilizies dynamic braking. A complete computer simulation of the two systems has been prepared, and computer records are presented which show the performance of the two systems.

GLOSSARY OF ANALOG COMPUTER SYMBOLS

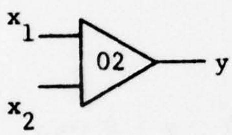
Symbol	Explanatory Notes

Pots

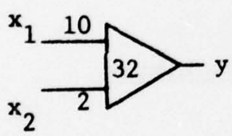


$y = .3775\ x$
Example of pot P25 set at .3775. Pot coefficients are always less than 1.

Summing Amplifiers

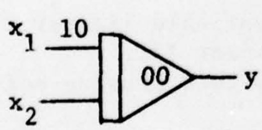


$y = -x_1 - x_2$
Example of A02 used to add two variables x_1 and x_2. If no gain on the input line is indicated it is assumed to be one.



$y = -10x_1 - 2x_2$
Example showing input gains other than one.

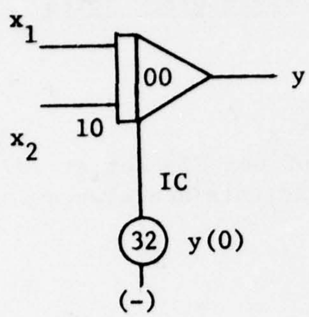
Integrator with Zero Initial Condition



$$y = -\int_0^t (10\ x_1 + x_2)\ dt$$

Integrator A00 with a gain of 10 for the x_1 input and one for the x_2 input.

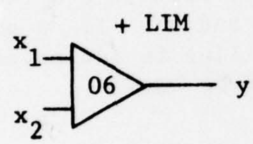
Integrator with Initial Condition y(0)



$$y = -\int_0^t (x_1 + 10x_2)\, dt + y(0)$$

Example of integrator A00 with initial condition y(0).

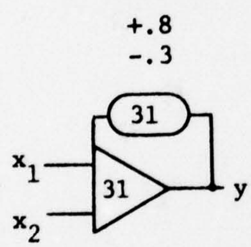
Summing Amplifier with Positive Limiter



$y = -(x_1 + x_2)$ $\quad y > 0$ only

Amplifiers may also have negative limiters and are designated by - LIM.

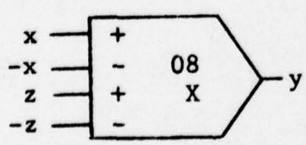
Summing Amplifier with Variable Positive and Negative Limits



$y = -(x_1 + x_2) \qquad y < .8$
$\qquad\qquad\qquad\quad y > -.3$

Example of variable limiter 31 around amplifier A31.
Variable limiters provide soft limiting.

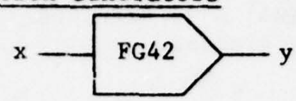
Multipliers



$y = -xz$

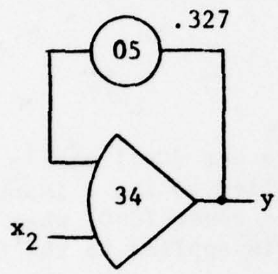
Both positive and negative inputs must be provided. Multipliers may also be set up to divide and take square roots.

Function Generators



$y = f(x)$
Diode function generators approximate a function by straight line segments. Up to 20 segments are possible. Fixed diode function generators for generating the sine and cosine functions are available.

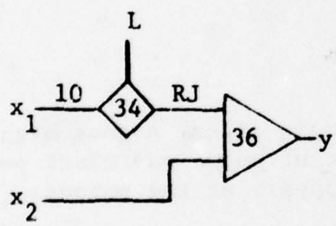
High-Gain Summing Amplifier



$$y = -\frac{1}{.327} x_2$$

Example of A34 used as a high-gain amplifier to multiply variable x_2 by the reciprocal of the setting of pot P05.

Summary Amplifier with Electronic Switch Input

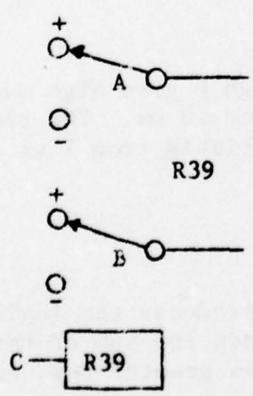


$y = -x_2 - 10x_1$ when $L = 1$

$y = -x_2$ when $L = 0$

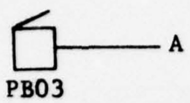
Logic signal L connects the input x_1 to the amplifier when high.

Mechanical Relays



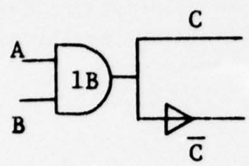
Mechanical relays are double pole double throw. When the logic signal, C, to the coil is high, the relays are in the positive position as shown.

Push Button



Logic signal A is high when button is pressed.

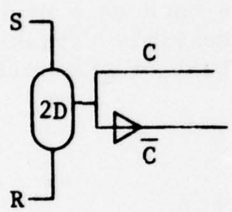
AND Gate and Inverter



$C = A \cdot B$

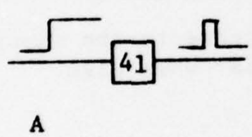
$\overline{C} = \overline{(A \cdot B)}$

Register



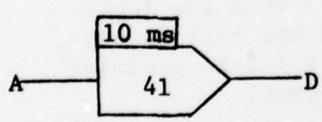
Registor is set (C=1) when a logic one is applied to the S input. Registor is reset (C=0) when a logic one is applied to the R input.

Differentiator



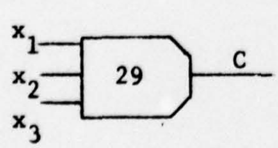
When logic signal A goes high and output pulse one clock period long appears at the output.

Monostable



When A goes high D goes high and remains high for 10 ms. The time duration is variable from 1 μs to 100 seconds.

Comparator



Comparator 29 produces the logic signal C = 1 when the sum of the analog inputs is greater than zero.

APPENDIX NO. 5

40,000 HORSEPOWER PER SHAFT DRIVE,
CONTROL SYSTEM LOGIC

5

WESTINGHOUSE ELECTRIC CORPORATION

MARINE DIVISION

SUNNYVALE, CALIFORNIA 94088

40,000 HP/Shaft Control System Logic

The following section is intended to supplement Section 3.6 of the main report, emphasizing the control logic of the Master Control Unit (MCU) in detail.

3.6 CONTROLS

Major emphasis is placed upon the central part of the control system, the master control unit which comprises the dynamic control section, lower level supervisory control section, and upper level supervisory control section.

In part 3.6.1, the general organization of the control system is presented and the function of each of the three sections of the master control unit is given. A detailed description of these sections is given in parts 3.6.2, 3.6.3, and 3.6.4.

3.6.1 Overview

3.6.1.1 Organization

The general organization of the control system is illustrated by the block diagram in Figure 3.6-1. The master control unit which is the central part of the control system is divided into three sections as indicated by the three control blocks.

The inputs to the master control unit consist of operator commands from the control console, parameters sensed in the propulsion system (e.g. currents, voltages, etc.), and feedback information from other control units.

The master control unit generates inputs to the gas turbine controls, switch controls, exciter controls, and dynamic resistor controls.

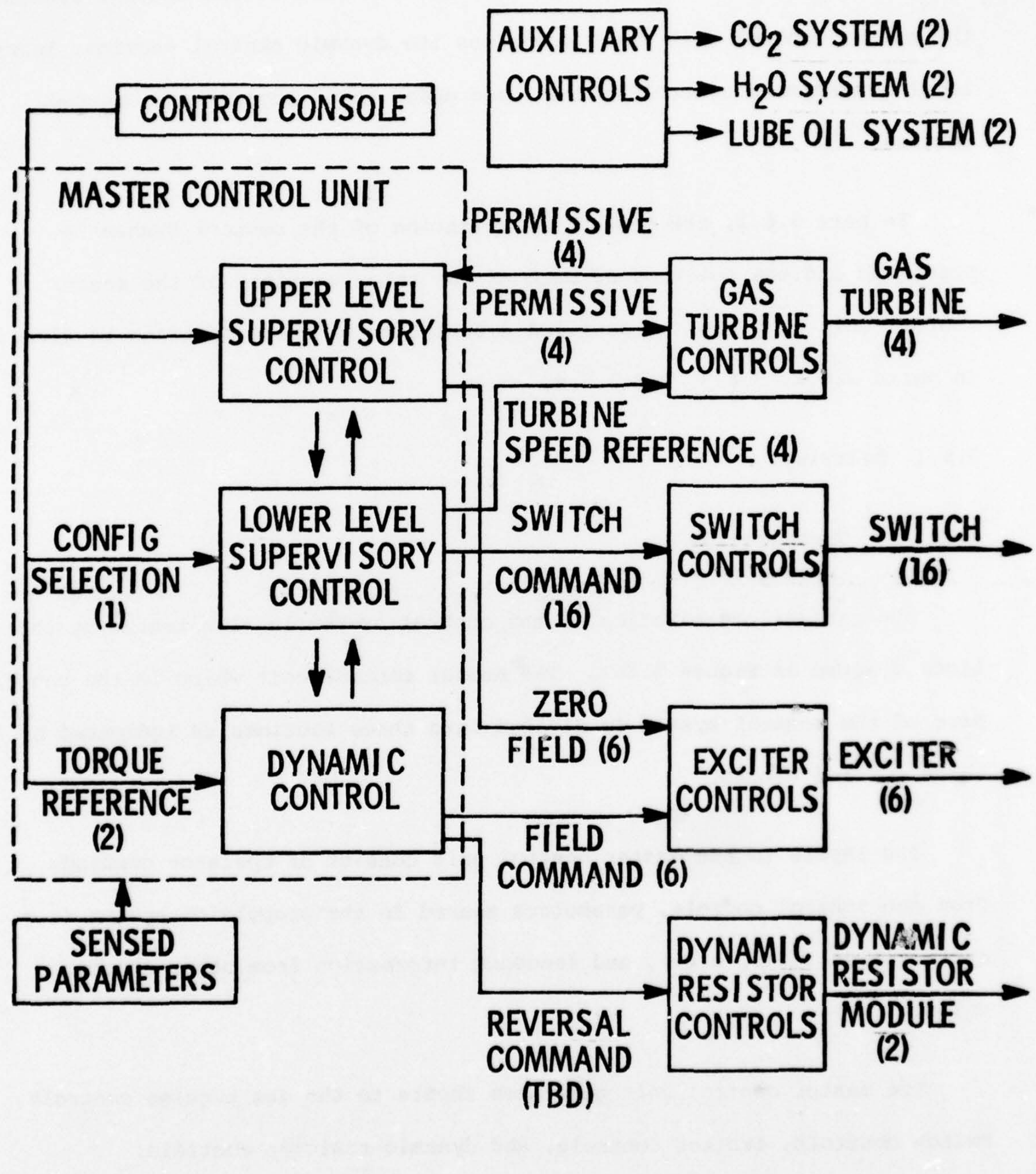


Figure 3.6-1 Master Control Unit Block Diagram

The auxiliary controls for the CO_2 systems, H_2O systems, and lube oil systems are regulated at the local level. Although the master control unit does not command these systems, it assesses the status of each via selected sensed parameters (e.g. lube oil pressure).

The start up and shut down of the gas turbines are under local control, however, there is a permissive interlock between the gas turbine controls and the master control unit. Also, the gas turbine controls adjust the fuel flow rate in striving to match each power turbine speed with its respective reference speed which is input from the master control unit.

The switch controls open and close the switches in the SEGMAG power circuit in response to the sixteen switch commands generated by the master control unit.

The exciters, including their controls, are energized locally. Each exciter provides a source of variable dc voltage for a single machine field. In response to the field commands from the master control unit, the exciter controls vary the voltage output from each exciter and thus the field currents. In addition, the field currents may be rapidly forced to zero by giving a second set of commands (i.e. zero field) from the master control unit.

The dynamic resistor controls activate the dynamic resistor modules in response to commands from the master control unit. These commands are only given during reversal (i.e. crash back).

3.6.1.2 Functions

The control functions performed by each of the three sections of the master control unit are highlighted in Figure 3.6-2 and expanded upon in the paragraphs to follow. The functions for each section are split into two categories, conditional and continuous. The conditioal category is further divided into active mode and passive mode.

The function of the dynamic control section is to control the propulsion system in response to the starboard and port torque references. This is accomplished through the field commands to the exciter controls and the reversal commands to the dynamic resistor controls. The manner in which the exciters and dynamic resistor modules are controlled depends upon the power configuration.

The field commands are continuously controlled as functions of the power configuration, reference torques, and electromagnetic torques developed by the motors. Part or all of these commands are overridden whenever any one of the three control sections is in the active mode.

In the passive mode, the dynamic control determines if a propeller reversal is required. Whenever this condition arises, the active mode is initiated and a propeller reversal is achieved by executing a fixed program.

CONTROL SECTION	CONTROL FUNCTION		
	CONDITIONAL		CONTINUOUS
	MODE/RESPONSE	ACTIVE MODE CONDITION(S)	
UPPER LEVEL SUPERVISOR	Active/Take over lower level supervisor and dynamic control functions Passive/Detect occurrence of conditions	• Start up • Shut down • Restart • Emergency • Fault	• Permissives
LOWER LEVEL SUPERVISOR	Active/Take over all field commands Switch position commands Passive/Detect if a transition is required Switch position commands static	• Transition	• Turbine speed references
DYNAMIC	Active/Reversal commands Take over generator field commands Passive/Detect if a reversal is required Reversal commands static	• Reversal	• Generator and motor field commands (unless overridden)

Figure 3.6-2 Master Control Unit Functions

The lower level supervisory control performs the functions of configuration control and generation of turbine speed references. In the passive mode, the operator selected configuration is compared with the configuration in which the propulsion system is operating. If they differ, the active mode is initiated and a transition is performed which establishes a new configuration by changing switch positions.

The most important functions of the upper level supervisor are of the conditional type. In the passive mode, the system is monitored for the occurrence of five categories of conditions which are anticipated to arise infrequently. When one of these conditions occurs, the upper level supervisor takes over control of the propulsion system (active mode). A brief description of each condition follows:

START

Each time the control system is energized, a start up sequence is carried out which readies the system for operation.

STOP

Before deenergizing the control system, the stop sequence is carried out which provides for an orderly shut down of the propulsion system.

RESTART

Upon detecting a system malfunction, a restart sequence is carried out which places the control system and propulsion system in the states they would be in at the end of a start up sequence.

EMERGENCY

Emergency conditions are any occurrences which require immediate and rapid shut down of the propulsion system with the exception of electrical faults in the SEGMAG armature circuit(s).

FAULT

Upon detecting a fault, the machine fields are immediately forced towards zero and the propulsion system is rapidly shut down.

In addition to the conditional control functions given above, the upper level supervisor also provides a permissive interlock with the gas turbine controls. For instance, in order for the gas turbines to be allowed to run certain conditions must be met, e.g. the lube oil systems must be operating.

3.6.1.3 Sensed Parameters

Although numerous sensors are located throughout the propulsion system, only those sensed parameters which are input to the master control unit are discussed here. Figure 3.6-3 shows the major components of the propulsion system and indicates the location of the sensors exclusive of those in the CO_2 systems, H_2O systems, and lube oil systems.

To recapitulate from section 2, each SEGMAG generator (GT1 through GT4) is driven directly by a gas turbine (GT1 through GT4). Each SEGMAG motor (M1 and M2) is directly coupled to a propeller. Each SEGMAG machine is separately excited (EX G1 ... EX M2). Located in the electrical power

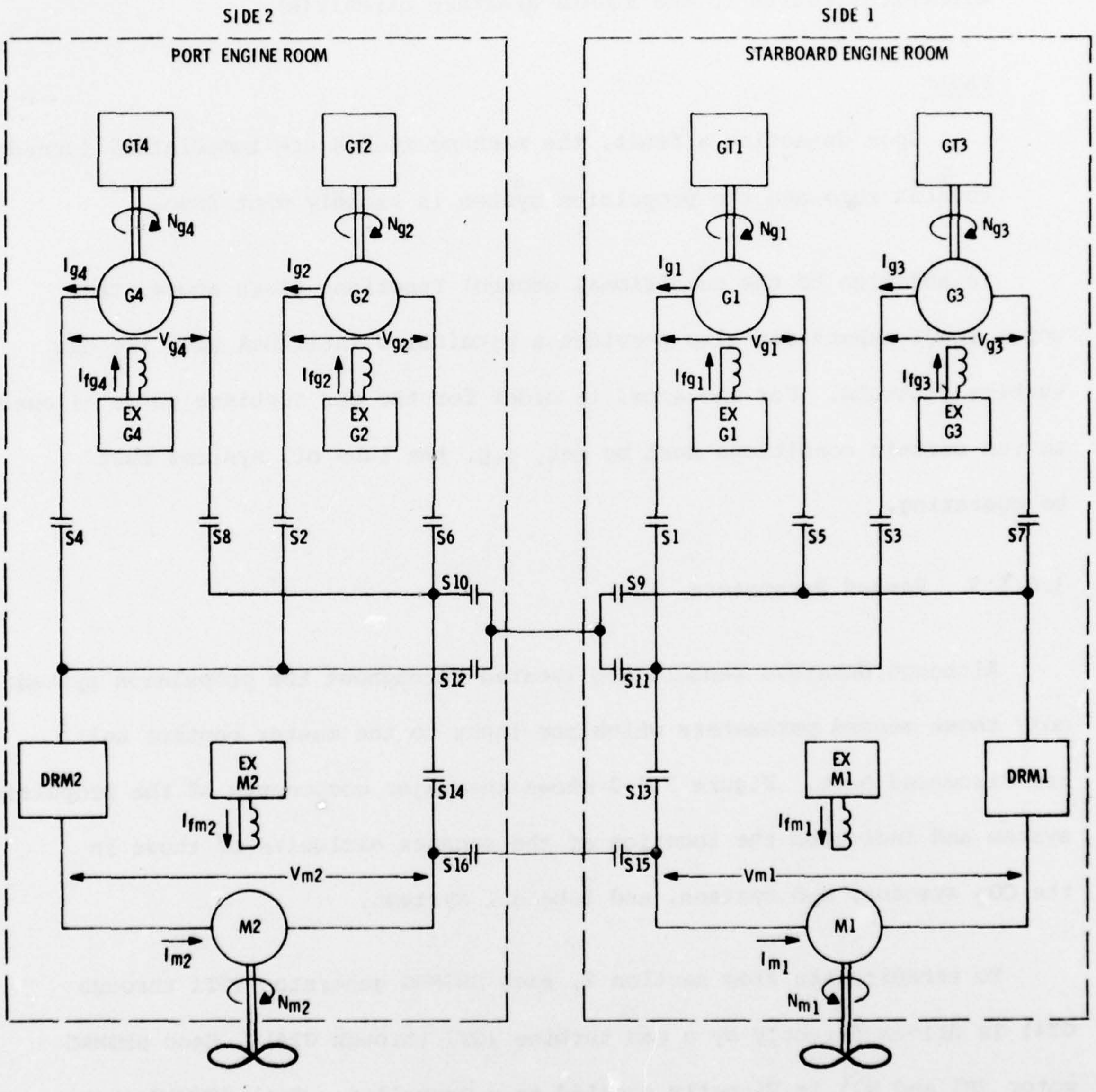


Figure 3.6-3 Propulsion System Sensors

circuit are sixteen switches (S1 through S16) and two dynamic resistor modules (DRM1 and DRM2).

The sensed parameters indicated in Figure 3.6-3 are listed below:

$N_{g1} \ldots N_{g4}$,	Generator-power turbine rotational speed
$V_{g1} \ldots V_{g4}$,	Generator voltage
$I_{g1} \ldots I_{g4}$,	Generator current
$I_{fg1} \ldots I_{fg4}$,	Generator field current
N_{m1}, N_{m2},	Motor-propeller rotational speed
V_{m1}, V_{m2},	Motor voltage
I_{m1}, I_{m2},	Motor current
I_{fm1}, I_{fm2},	Motor field current
S1...S16,	Switch position

By definition, all speeds, voltages, and currents are considered positive when the ship is being driven ahead. In driving astern, the generator rotational speeds and motor field currents remain positive while all others are negative in value. The switch position parameters are of type logical, being true (logical 1) when the switch is closed and false (logical 0) when the switch is open.

At each SEGMAG machine, critical parameters are sensed which pertain to the CO_2, H_2O, and lube oil systems. The make up of these parameters is to be determined. The purpose of these parameters is to ascertain the status of the three systems and thereby establish whether or not a SEGMAG machine may be included in the propulsion system.

3.6.1.4 Supplementary Information

The detailed description of each control section in parts 3.6.2, 3.6.3, and 3.6.4 makes extensive use of block diagrams. An explanation of the block diagram symbols is given in Figure 3.6-4.

Also, when numerical values are given, they will usually be on a p.u. (per unit) basis. The base values and ranges of pertinent parameters are listed in Table 3.6-1. For any given parameter, the physical value is the product of the per unit value and base value. For instance, if the motor speed is 0.5 p.u., the physical rotational speed is then 0.5 x 168 rev/min = 84 rev/min.

Table 3.6-1. Parameter Base Values and Ranges

Parameter	Base Value	Nominal Range, p.u.
Generator:		
Voltage	2000 V	-1.0 to +1.0
Current	7500 A	-1.3 to +1.3
Field Current	224 A	-1.15 to +1.15
Power	15000 kW	0 to +1.0
Speed	3600 rev/min	0 to +1.0
Motor:		
Voltage	2000 V	-1.0 to +1.0
Current	15000 A	-1.0 to +1.0
Field Current	1391 A	0 to +1.0
Power	30000 kW	0 to +1.0
Speed	168 rev/min	-1.0 to +1.0
Torque	1705 kNm	-1.0 to +1.0

Note: During reversal the generator currents, motor currents, and motor torques may exceed the limits shown by approximately 50 percent. In addition, the motor power becomes temporarily negative.

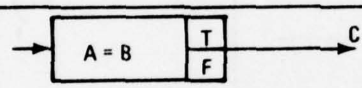
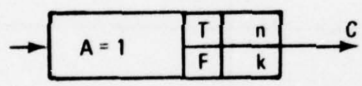
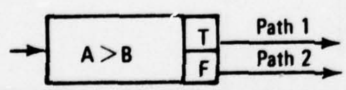
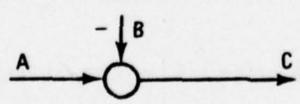
NAME	SYMBOL	DESCRIPTION
LOGICAL RELATIONAL OPERATORS	= ≠ < ≤ > ≥	Equal to Not equal to Less than Less than or equal to Greater Greater than or equal to
LOGICAL OPERATORS	.AND. .OR.	And Or
LOGICAL EXPRESSION (VALUE)		C is true (logical 1) if A = B C is false (logical 0) if A ≠ B
		C = n if A = 1 C = k if A ≠ 1 Note: If A is a logical parameter then C = n if A is true (logical 1). If A is false (logical 0) then C = k.
(BRANCH)		Path 1 is followed if A > B Path 2 is followed if A ≤ B
SUMMER		C = A – B

Figure 3.6-4a Block Diagram Symbols

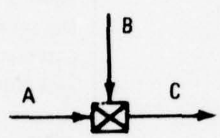
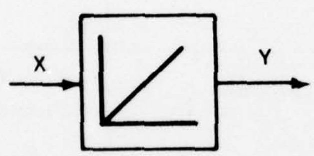
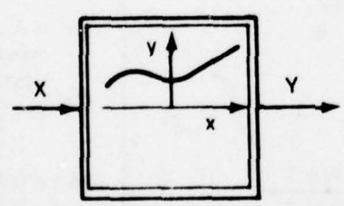
NAME	SYMBOL	DESCRIPTION
MULTIPLER		$C = A \times B$
INTEGRATOR		$y = \int x\,dt$
FUNCTION		$y = f(x)$

Figure 3.6-4b Block Diagram Symbols

3.6.2 Dynamic Control

3.6.2.1 Functions

The function of the dynamic control is to control the machine fields and dynamic resistor modules in response to the torque references.

Six field commands are continuously generated as functions of the reference torques, motor torques, and power configuration. Unless overridden, each command provides the error signal input to one of the six exciters. The field characteristics under steady state operating conditions are shown in section 2.3.1.2.1 as functions of motor speed and power configuration.

In the passive mode, the dynamic control monitors the sign (i.e. plus or minus) of the torque references and propeller speeds. If the signs are not identical, a change to the active mode is made and a propeller reversal is achieved by executing a fixed program. This program regulates the generator and motor field commands and sequences the reversal commands to the dynamic resistor modules in a predetermined manner.

3.6.2.2 Input/Output

Figure 3.6-5 shows the dynamic control section input and output. Also shown is a simplified block diagram which is described in the next section.

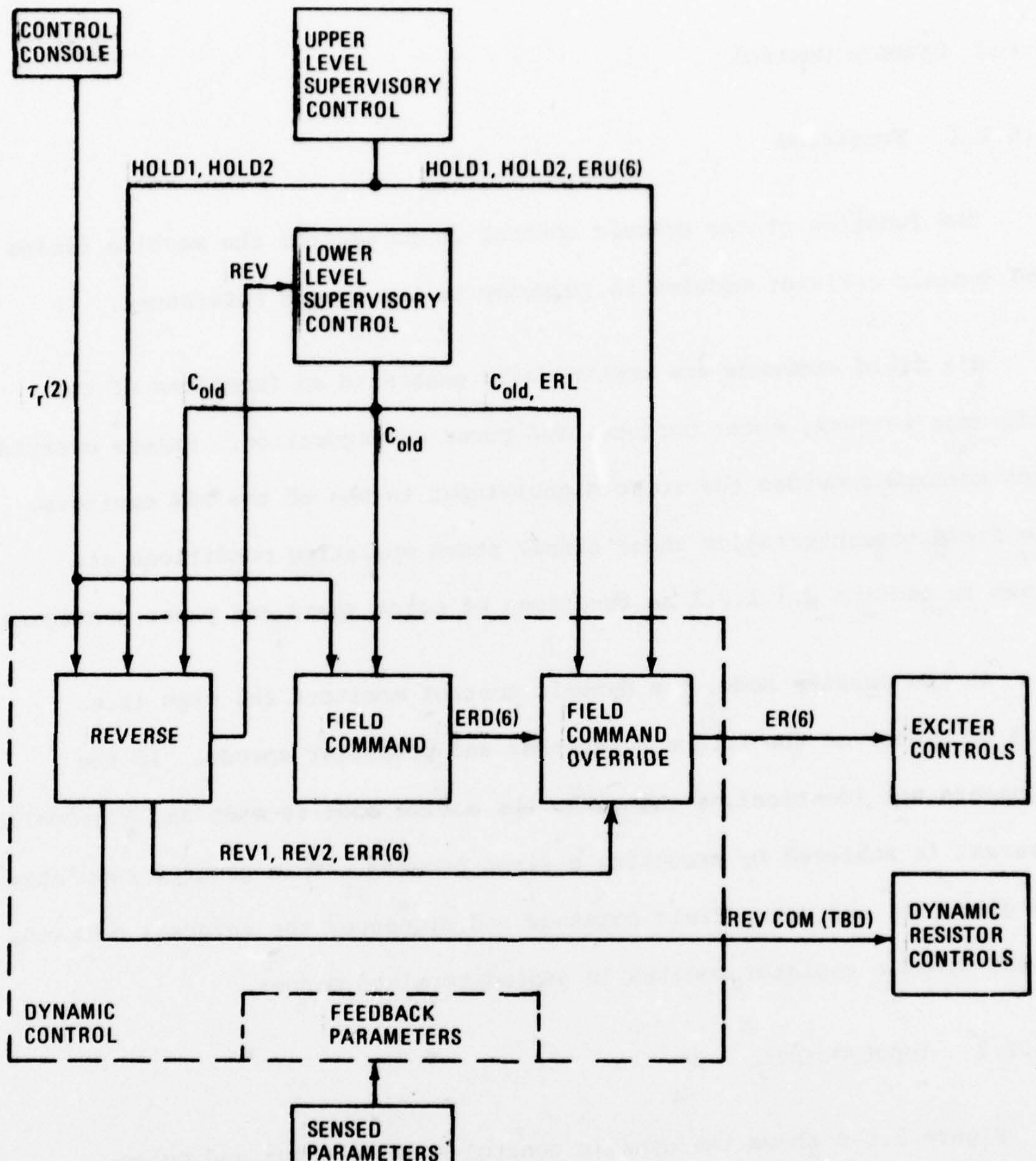


Figure 3.6-5 Dynamic Control Input/Output and Block Diagram

The input and output parameters are listed in Tables 3.6-2 through 3.6-8. The symbol and total number for each parameter are shown. Also, the type of signal (i.e. logical, variable, etc.) and a brief description of each parameter are given.

Table 3.6-2 lists the inputs from the console which are the starboard (side 1) and port (side 2) torque references. Each may be varied by the operator within the range of -1.0 p.u. to +1.0 p.u.

Table 3.6-2. Console Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
(τ_r) τ_{r1} τ_{r2}	2	Variable	Torque references for side 1 and side 2.

Table 3.6-3. Dynamic Control Sensor Signals and Feedback Parameters

Sensor Signal Symbol	Feedback Parameter Symbol	Total Number	Type	Description
I_{mx}	--	2	variable	Motor X current
I_{fmx}	I_{fmx}	2	variable	Motor X field current
--	τ_{mx}	2	variable	Motor X electromagnetic torque
N_m	N_m	2	variable	Motor X speed
I_{gx}	I_{gx}	4	variable	Generator X speed
V_{gx}	V_{gx}	4	variable	Generator X voltage
I_{fgx}	I_{fgx}	4	variable	Generator X field current

Note: "X" in the symbols has the values 1 thru "total number."

Table 3.6-4. Lower Level Supervisor Control Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
C_{old}	1	discrete variable	Gives the configuration in which the propulsion system is operating: I, Z, Q, H, or F. During transition, C_{old} has the value NC.
(ERL) ERL_{g1} ERL_{g2} ERL_{g3} ERL_{g4} ERL_{m1} ERL_{m2}	6	variable	Field commands-only used during transition.

Table 3.6-5. Upper Level Supervisor Control Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
HOLD1	1	logical	Upper level is in the passive mode (logical 0) or active mode (logical 1) with respect to side 1.
HOLD2	1	logical	Upper level is in the passive or active mode with respect to side 2.
(ERU) ERU_{g1} ERU_{g2} ERU_{g3} ERU_{g4} ERU_{m1} ERU_{m2}	6	variable	Field commands-only used when upper level is in the active mode.

Table 3.6-6. Dynamic Control Inputs to the Lower Level Supervisory Control

Symbol	Total Number	Type	Description
REV	1	logical	During reversal, the dynamic control is in the active mode (logical 1).

Table 3.6-7. Dynamic Control Inputs to the Exciter Controls

Symbol	Total Number	Type	Description
(ER) ER_{g1} ER_{g2} ER_{g3} ER_{g4} ER_{m1} ER_{m2}	6	variable	Field command error signals, one per exciter.

Table 3.6-8. Dynamic Control Inputs to the Dynamic Resistor Controls

Symbol	Total Number	Type	Description
REV COM	TBD	logical	Activates the dynamic resistors.

Table 3.6-3 lists the 18 sensor signals required by the dynamic control. Of these, all but the motor current signals, I_{m1} and I_{m2}, are used directly as feedback parameters.

The value of the motor current, I_m, is multiplied by the motor field current, I_{fm}, in order to obtain the feedback parameter T_m which is the motor electromagnetic torque. The above formulation is on a per unit basis and applies to both sides.

Table 3.6-4 lists the inputs from the lower level supervisor. When the lower level is in the passive mode, the discrete variable C_{old} identifies which of the five configurations the propulsion system is operating in. In the active mode, i.e. during transition, it is given the value "NC."

The six field commands are only used as input to the exciter controls during transition.

Table 3.6-5 lists the inputs from the upper level supervisory control. The logical parameters HOLD1 and HOLD2 which apply to side 1 and side 2 respectively indicate if the upper level is in the passive or active mode.

The six field commands are only used as input to the exciter controls when the upper level is in the active mode.

Table 3.6-6 shows the logical parameter REV which is input to the lower level supervisory control. During a reversal, REV has the value of 1 with the result that the lower level is inhibited from making a configuration change.

Table 3.6-7 lists the exciter control inputs from the dynamic control. There is one error signal for each of the six machine exciters. A positive error signal results in increasing the field current in the positive direction. With a zero input, the field current is held constant. A negative error signal reduces the value of the field current.

Table 3.6-8 shows the dynamic resistor module inputs from the dynamic control. The number of signals is not yet established.

3.6.2.3 Block Diagram

Following a brief discussion of the roll played by each of the three blocks in the dynamic control section (Figure 3.6-5), a description of the internal functioning of each is given.

The FIELD COMMAND block strives to match the motor torques with the reference torques through six field command error signals (ERD). These continuously generated error signals pass through the FIELD COMMAND OVERRIDE block unaltered and are input to the exciter controls (ER) as long as all three control sections are in the passive mode. In the active mode, part or all of the FIELD COMMAND error signals are replaced by error signals from the REVERSE block (ERR), the lower level supervisor (ERL), or the upper level supervisor (ERU).

The modes of the three control sections are indicated by the values of C_{old}, HOLD1, HOLD2, REV1, and REV2.

The REVERSE block contains the logic for detecting the need for a reversal and the programs for carrying out same.

3.6.2.3.1 FIELD COMMAND Block

The FIELD COMMAND block generates error signals for each machine exciter in response to the reference torques. The manner in which these error signals are determined depends upon the power configuration, there being five basic arrangements which correspond to the five configurations: full power, half power, quarter power, zero power, and idle. In the following, a (typical) arrangement for each configuration is described.

Figure 3.6-6 shows the field command diagram for the full power configuration. The error signal for generator exciter 1, ERD_{g1}, is equal to the torque error on side one, i.e. the reference torque τ_{r1} minus the motor torque τ_{m1}. Thus the field of generator 1 responds directly to the torque error.

If the reference torque is greater than the motor torque, the error signal ERD_{g1} is positive which causes the field of generator 1 to increase. When the motor torque matches the reference torque, the error signal to generator exciter 1 is zero and the field is held at a constant value. If the torque error is negative, the field of generator 1 decreases in value.

The error signal for generator exciter 3, ERD_3, is the difference between the armature currents of generators 1 and 3. The error signal is zero only when the two currents balance each other. These two generators

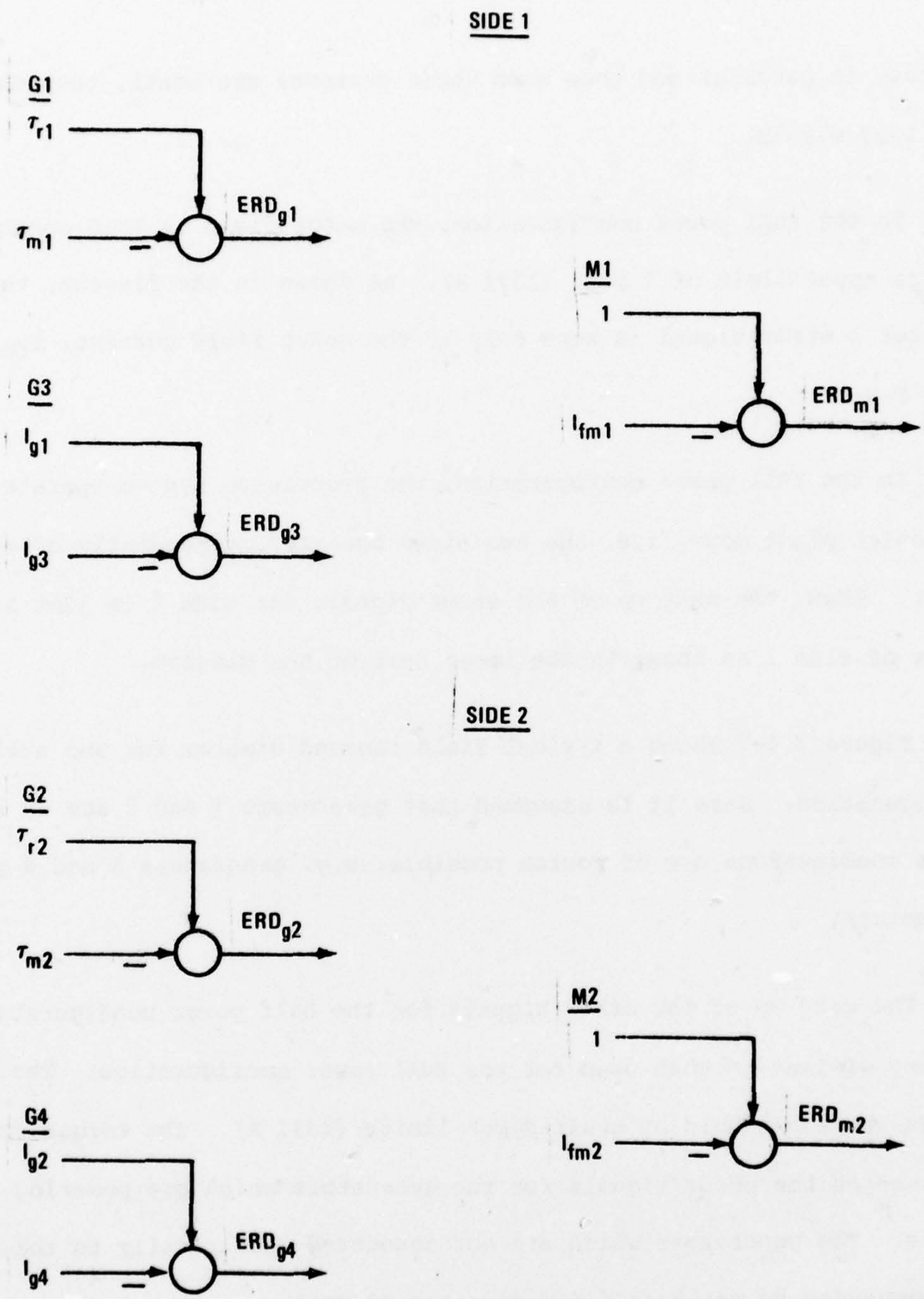


Figure 3.6-6 Field Command Diagram, Full Power Configuration

operate in parallel and thus when their currents are equal, they share the load evenly.

In the full power configuration, the motor field is held constant at its upper limit of 1 p.u. (1391 A). As shown in the diagram, the motor exciter 1 error signal is zero only if the motor field current, I_{fm1}, is 1 p.u.

In the full power configuration, the propulsion system operates in the split plant mode, i.e. the two sides operate independently of each other. Thus, the make up of the error signals for side 2 is just a mirror image of side 1 as shown in the lower half of the diagram.

Figure 3.6-7 shows a typical field command diagram for the half power configuration. Here it is assummed that generators 1 and 2 are on line. Other combinations are of course possible, e.g. generators 3 and 4 powering the motors.

The make up of the error signals for the half power configuration is very similar to that used for the full power configuration. The motor fields are again held at their upper limits (1391 A). The torque errors are used as the error signals for the generators which are powering the motors. The generators which are not connected electrically to the motors are commanded to maintain field currents of zero.

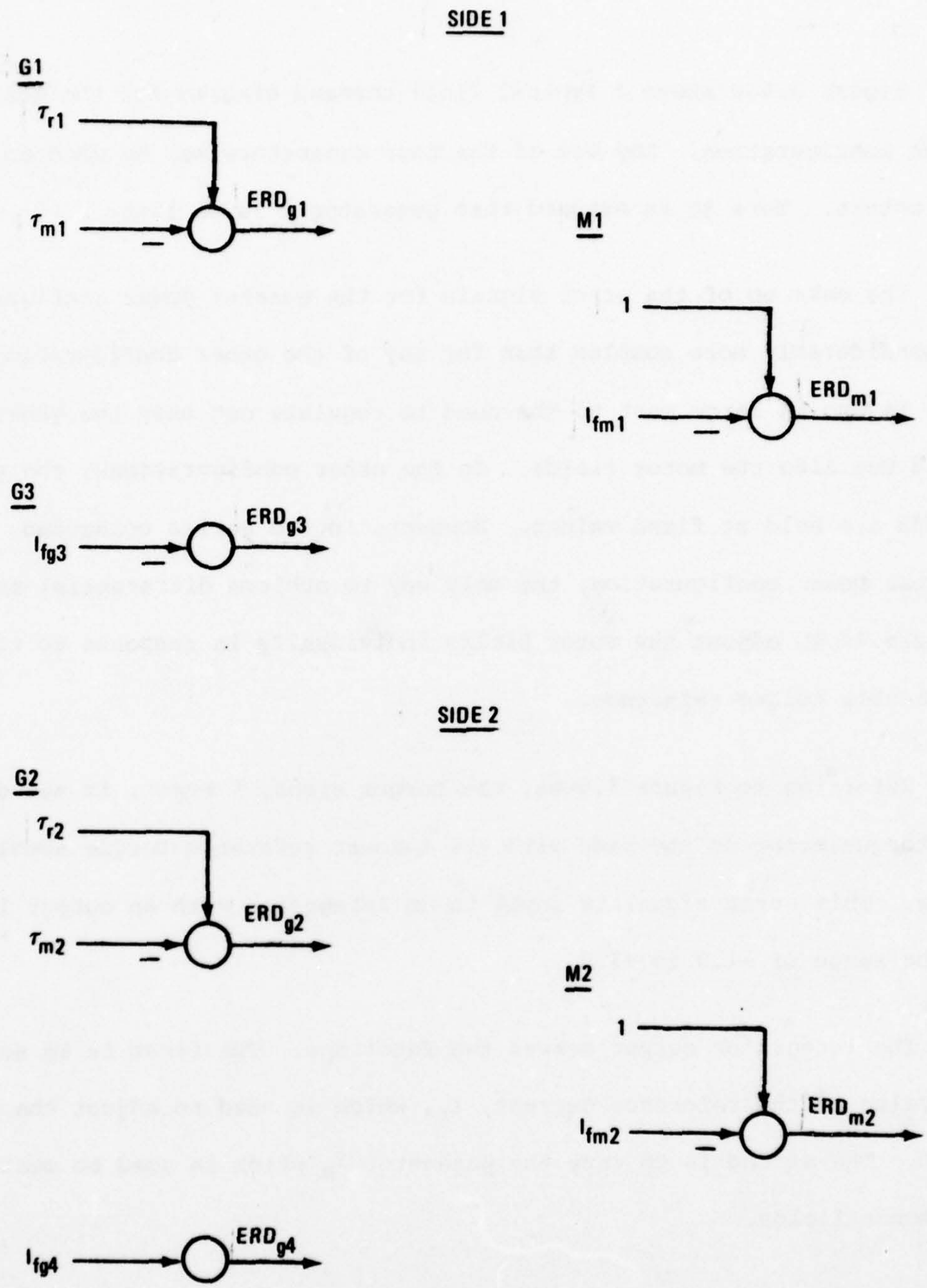


Figure 3.6-7 Field Command Diagram, Half Power Configuration (Typical)

Figure 3.6-8 shows a typical field command diagram for the quarter power configuration. Any one of the four generators may be used to power the motors. Here it is assumed that generator 1 is on line.

The make up of the error signals for the quarter power configuration is considerably more complex than for any of the other configurations. This is due in large part to the need to regulate not only the generator field but also the motor fields. In the other configurations, the motor fields are held at fixed values. However, in the series connected quarter power configuration, the only way to achieve differential motor torques is to adjust the motor fields individually in response to the applicable torque reference.

Referring to Figure 3.6-8a, the torque error, τ error, is set equal to the torque error on the side with the largest reference torque absolute value. This error signal is input to an integrator with an output limited to the range of -1.0 to +1.0.

The integrator output serves two functions. The first is to set the value of the reference current, I_r, which is used to adjust the generator field. The second is to vary the parameter α_m which is used to control the motor fields.

When the integrator output is within the range of -0.7 to +0.7, the reference current is proportional to the output and the parameter αm has a constant value of 0.7. Outside this range, the reference current is

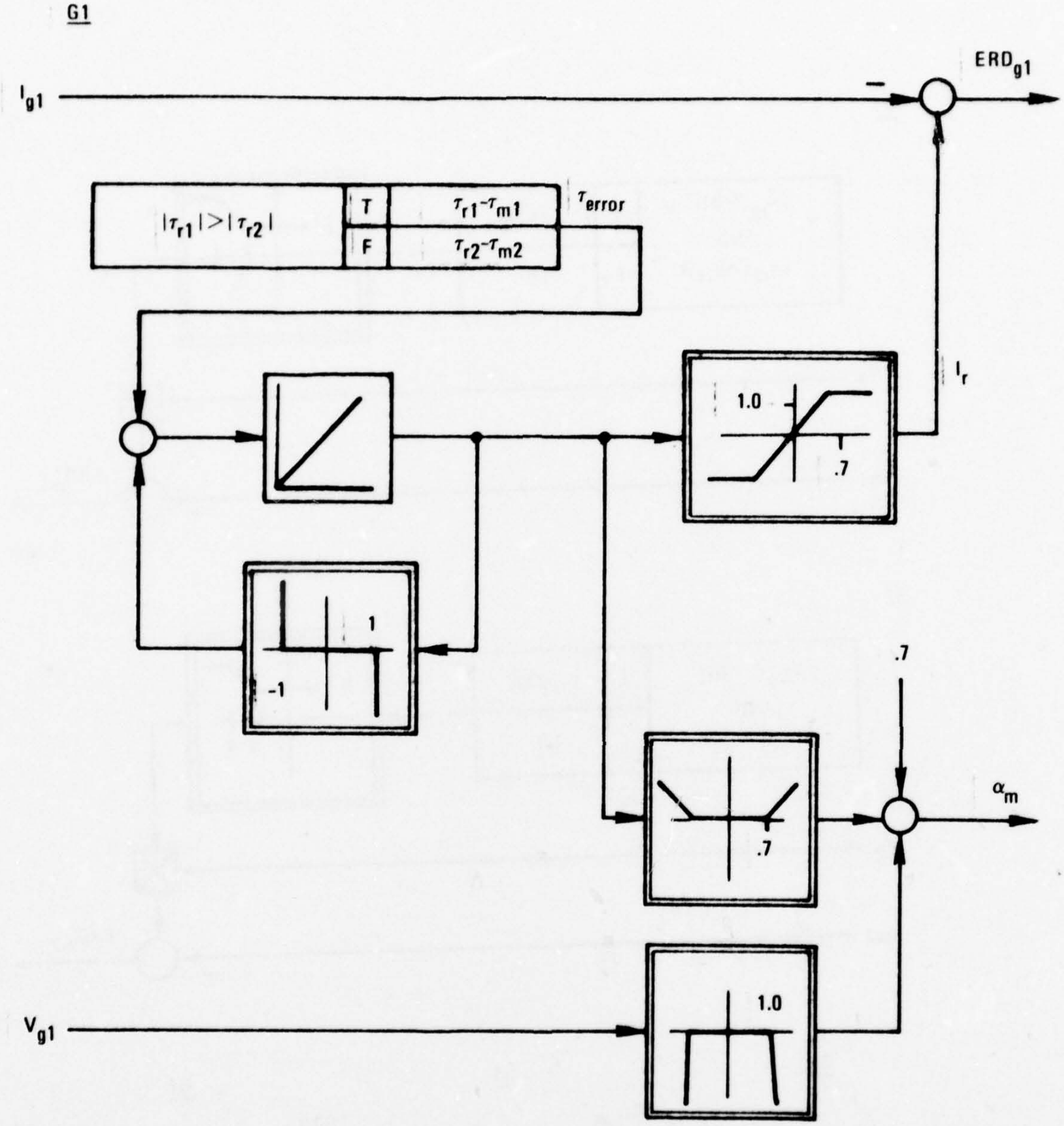


Figure 3.6-8a Field Command Diagram, Quarter Power Configuration (Typical)

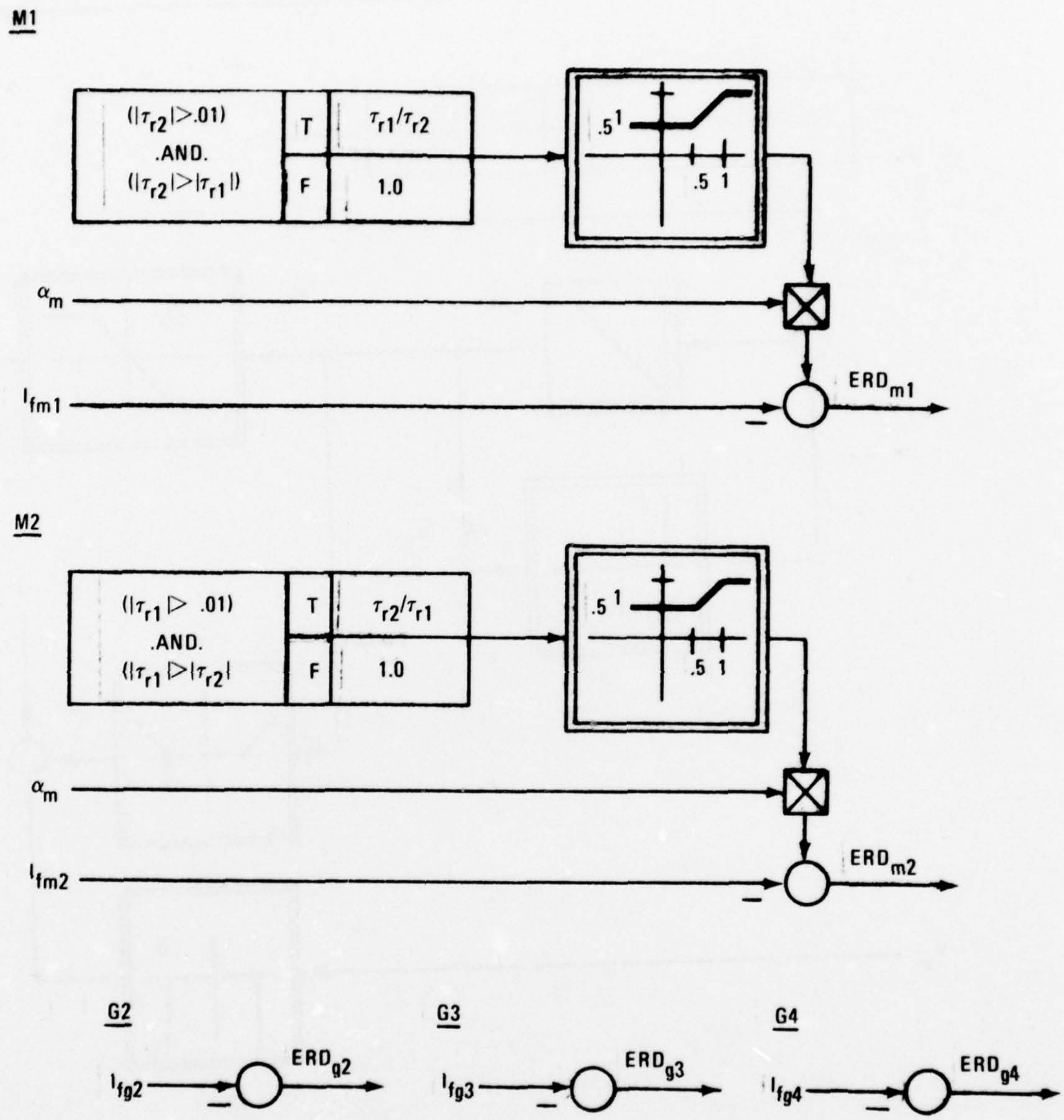


Figure 3.6-8b Field Command Diagram, Quarter Power Configuration (Typical)

limited to a value of plus or minus 1.0 ($\pm$7500A). The parameter α_m increases to a limiting value of 1.0 unless the generator voltage exceeds 1.0 (2000V). At the quarter power operating point under balanced steady state conditions, α_m would be 0.752 and the motor fields would have values of 0.752 p.u.

The motor exciter error signals, ERD_1 and ERD_2, are shown in Figure 3.6-8b. Under balanced conditions, i.e., equal reference torques, the motor fields are adjusted to equal α_m on a per unit basis. Under unbalanced conditions, the motor fields may be varied up to a ratio of 2 to 1. At very small reference torque values (-0.01 to +0.01) differential torque control is inhibited.

Figure 3.6-9 shows the field command diagram for the zero power configuration. The error signals to all generators are zero and thus the generator fields are not changed from the values they have after transition to this configuration. The motor fields are held constant at their upper limits.

This configuration serves as an intermediary between the idle, quarter power and full power configurations wherein all of the switches are open.

Figure 3.6-10 shows the field command diagram for the idle configuration. The error signals are such that all fields are commanded to produce zero current. The purpose of this configuration is to minimize the auxiliary electrical power consumption during extended periods when the ship is not being driven, but, at the same time, allowing one or more gas turbines to be at idle.

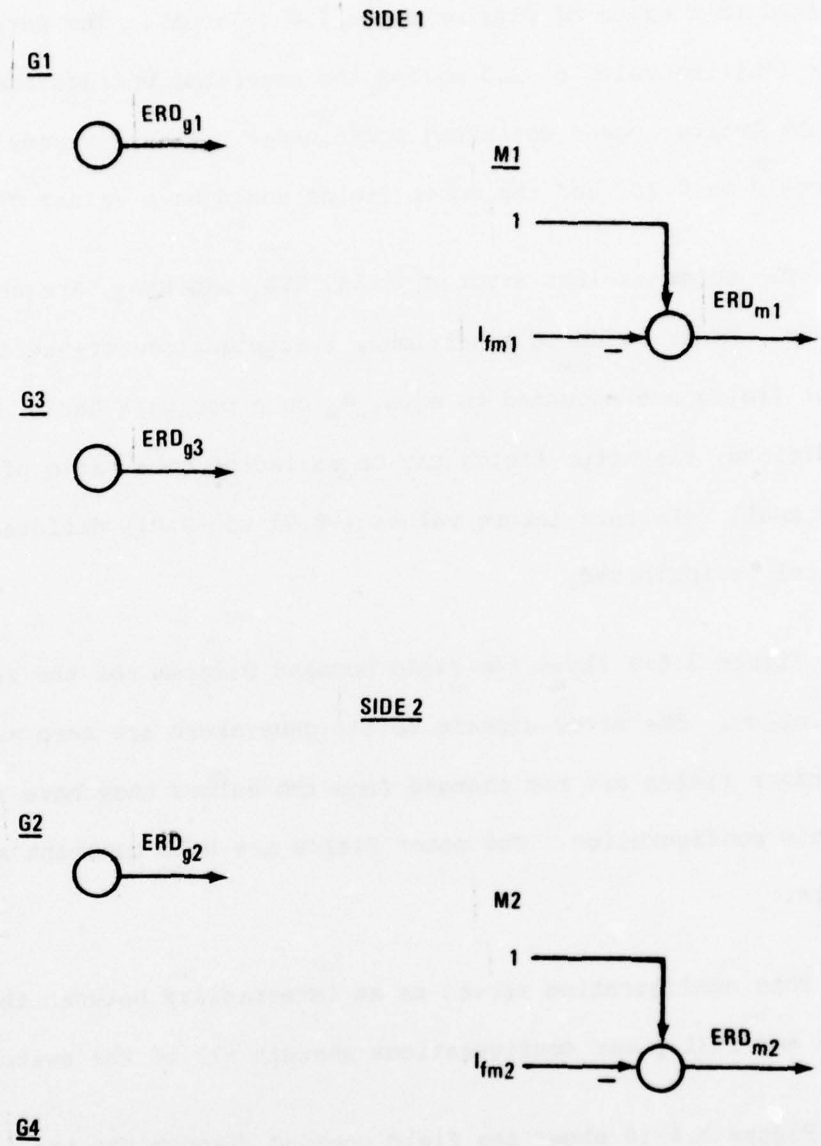


Figure 3.6-9 Field Command Diagram, Zero Power Configuration

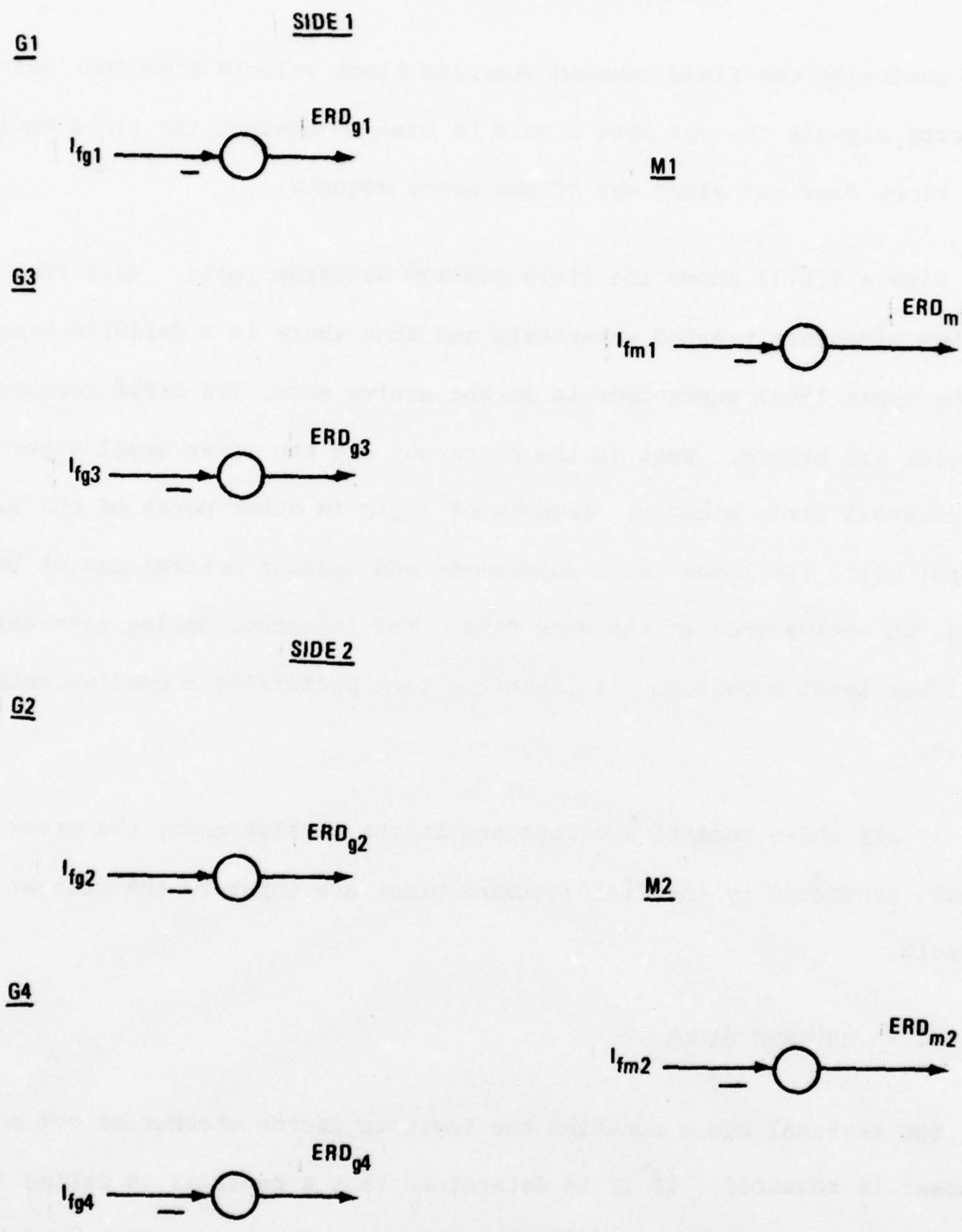


Figure 3.6-10 Field Command Diagram, Idle Configuration

3.6.2.3.2 FIELD COMMAND OVERRIDE Block

Basically the field command override block selects from four sets of error signals the set that should be used to control the field exciters. This block does not alter any of the error signals.

Figure 3.6-11 shows the field command override logic. Note that the two sides are treated separately and that there is a definite hierarchy. If the upper level supervisor is in the active mode, its field commands override all others. Next in the hierarchy are the lower level supervisor and reversal error signals. Because of logic in other parts of the master control unit, the lower level supervisor and dynamic control cannot both be in the active mode at the same time. For instance, during reversal the lower level supervisor is inhibited from performing a configuration change.

If all three control sections are in the passive mode, the error signals generated by the field command block are input to the exciter controls.

3.6.2.3.3 REVERSE Block

The reversal block contains the logic to decide whether or not a reversal is required. If it is determined that a reversal is called for, fixed programs are executed which direct the reversal process. Here the decision logic is given, however, the reversal programs which are based upon the analog simulation (see section ____) are only shown in outline form.

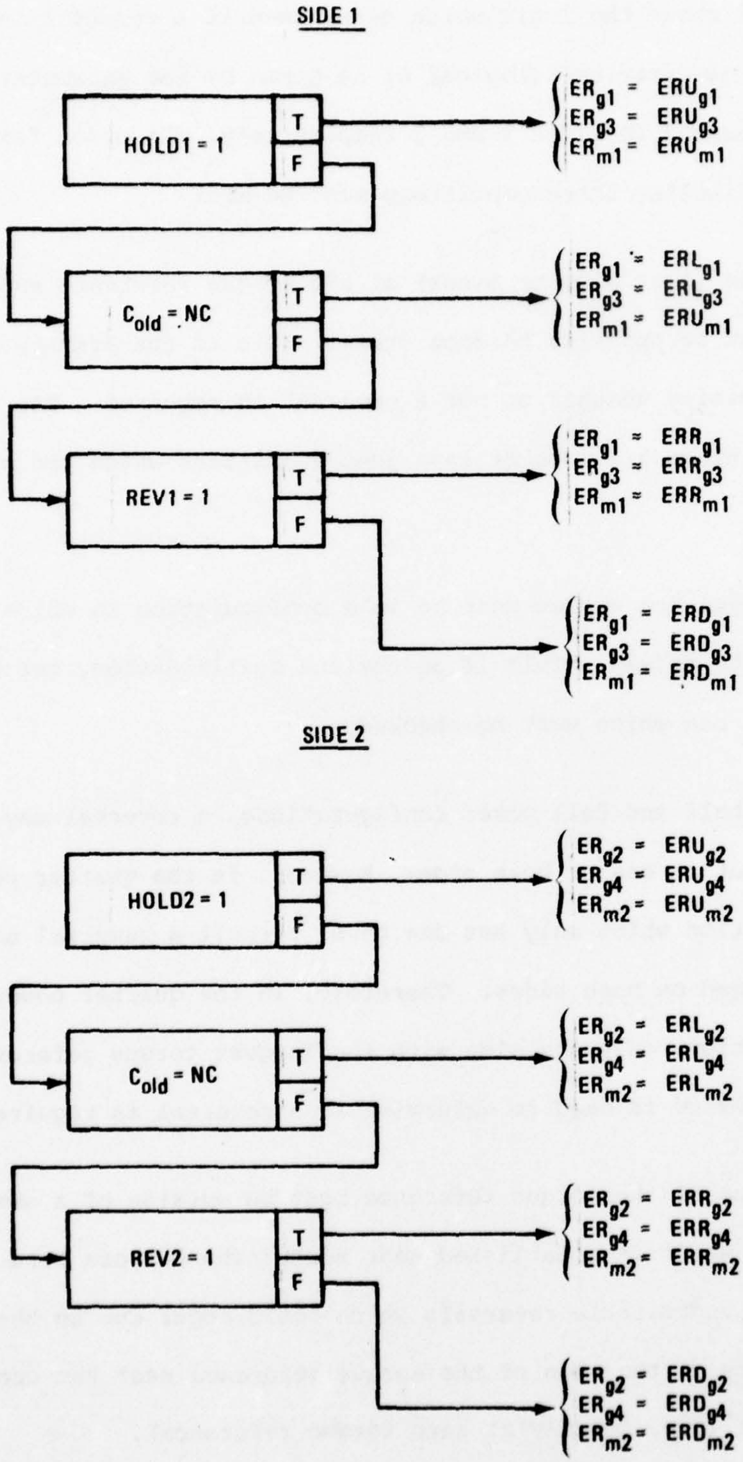


Figure 3.6-11 Field Command Override Logic

Figure 3.6-12 shows the logic which determines if a reversal is required (logical 1) or is not required (logical 0) as given by the parameters β_1 and β_2 which correspond to sides 1 and 2 respectively. In order for β_1 to be true, the following three conditions must be met:

1. The sign (i.e. plus or minus) of the torque reference and propeller speed must be opposite to each other. This is the primary means of determining whether or not a reversal is required. The last two conditions are more or less just qualifiers which are often true.

2. The propulsion system must be in a configuration in which the ship may be driven. This is an obvious qualification, but none the less, one which must be checked.

   In the half and full power configurations, a reversal may be carried out on one or both sides, however, in the quarter power configuration which only has one power circuit a reversal must be performed on both sides. Therefore, in the quarter power configuration, only the side with the largest torque reference absolute value is used to determine if a reversal is required.

3. The value of the torque reference must be outside of a small dead band which is established near zero. The purpose here is to negate undesirable reversals which could occur due to the uncertainty of the sign of the torque reference near the cross over point (i.e. ideally at zero torque reference).

SIDE 1

$\left\{ \mathrm{SIGN}\,(\tau_{r1}) \neq \mathrm{SIGN}\,(N_{m1}) \right\}$

.AND.

$\left\{ [(C_{old} = Q).\mathrm{AND}.(|\tau_{r1}| \geq |\tau_{r2}|)].\mathrm{OR}.[C_{old} = H].\mathrm{OR}.[C_{old} = F] \right\}$

.AND.

$\left\{ [\tau_{r1} > 0.01].\mathrm{OR}.[\tau_{r1} < -0.01] \right\}$

T

F

β_1

SIDE 2

$\left\{ \mathrm{SIGN}\,(\tau_{r2}) = \mathrm{SIGN}\,(N_{m2}) \right\}$

.AND.

$\left\{ [(C_{old} = Q).\mathrm{AND}.(|\tau_{r1}| < |\tau_{r2}|)].\mathrm{OR}.[C_{old} = H].\mathrm{OR}.[C_{old} = F] \right\}$

.AND.

$\left\{ [\tau_{r2} > 0.01].\mathrm{OR}.[\tau_{r2} < -0.01] \right\}$

T

F

β_2

(REV1.EQ.1)

.OR.

(REV2.EQ.1)

T

F

REV

Figure 3.6-12 Reversal Logic

The logic for β_2 is essentially a mirror image of that for β_1.

There are five separate reversal programs: full power configuration sides 1 and 2, half power configuration sides 1 and 2, and quarter power configuration. Whenever $\beta 1$ or $\beta 2$ become true, one of these programs is executed. Figure 3.6-13 gives the general outline of the reversal programs. In the following paragraphs, some further explanatory notes are given.

At the start of a reversal program, the parameter REV1 is made true if a reversal is being performed on side 1. The same holds true for REV2 with respect to side 2. These two parameters cause the field commands generated by the reversal program(s) to be input to the exciter controls via the FIELD COMMAND OVERRIDE logic.

In addition, whenever REV1 or REV2 are true, REV is true which inhibits the lower level supervisory control from performing a transition.

Throughout steps 1, 2, and 3, if the reversal process is aborted if the applicable β becomes false which indicates that a reversal is no longer required. If necessary, the armature circuit is reclosed under reversal program control. The parameter(s) REV1 and/or REV2 are reset to logical 0 which returns control of the fields to the FIELD COMMAND block.

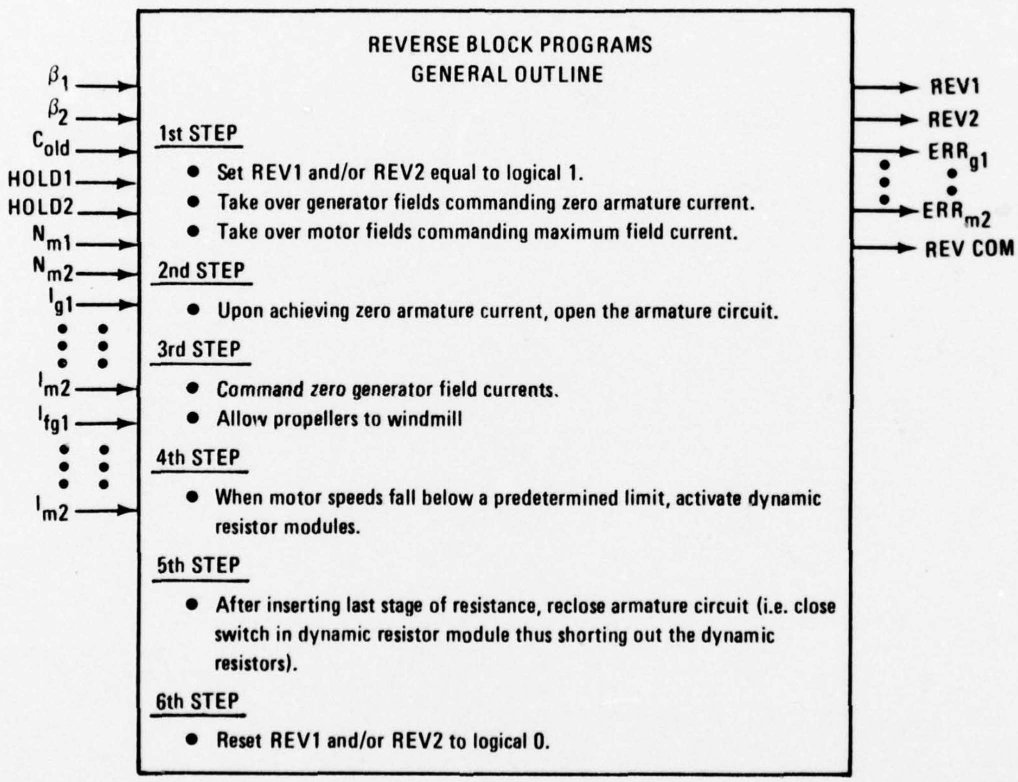


Figure 3.6-13 Reversal Programs

Once step 4 is initiated, the reversal process is carried out to completion with the sole exception being that if the upper level supervisory contro changes from the passive to the active mode, the reversal program(s) on the side(s) affected is/are immediately terminated.

3.6.3 Lower Level Supervisory Control

3.6.3.1 Functions

The lower level supervisory control performs the functions of configuration control and generation of the turbine speed references. For each turbine/generator, the load is continuously monitored and a speed reference is sent to the turbine controls which corresponds to the minimum gas turbine specific fuel consumption operating point.

In the passive mode the switch positions are not changed. The lower level supervisor compares the operator selected configuration with the configuration in which the propulsion system is operating. If they differ, and the SEGMAG machines for the new configuration are available, the active mode is initiated and a transition is performed per a fixed program. This program takes over all field commands and executes a predetermined sequence of steps which include changes in the switch commands.

3.6.3.2 Input/Output

Figure 3.6-14 shows the lower level supervisory control input and output. Also shown is a simplified block diagram which is described in the next section.

The input and output parameters are listed in Tables 3.6-9 through 3.6-15. The symbol and total number for each parameter is shown. Also, the type of signal is identified and a brief description of each is given.

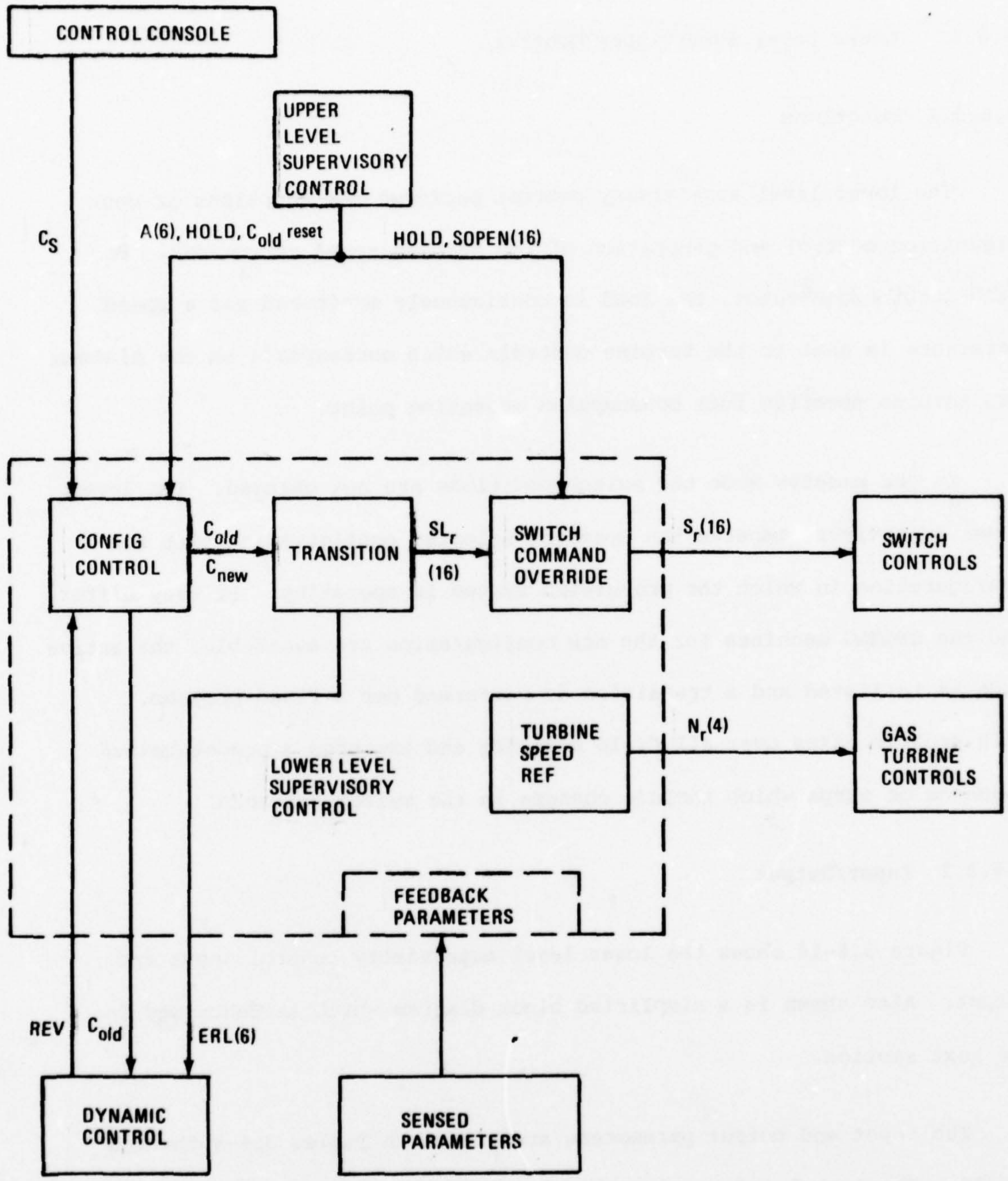


Figure 3.6-14 Lower Level Supervisory Control Input/Output and Block Diagram

Table 3.6-9 shows the console input which is the operator selected configuration. This may have any of four values, F, H, Q, and I, which correspond to the full power, half power, quarter power, and idle configurations.

Table 3.6-9. Console Inputs to the Lower Level Supervisor

Symbol	Total Number	Type	Description
C_s	1	discrete variable	Gives the selected configuration

Table 3.6-10. Lower Level Supervisor Sensor Signals and Feedback Parameters

Sensor Signal Symbol	Feedback Parameter Symbol	Total Number	Type	Description
I_{gx}	I_{gx}	4	variable	Generator X current
V_{gx}	V_{gx}	4	variable	Generator X voltage
I_{fgx}	I_{fgx}	4	variable	Generator X field current
V_{mx}	V_{mx}	2	variable	Motor X voltage
I_{fmx}	I_{fmx}	2	variable	Motor X field current
SX	SX	16	logical	Switch X position

Note: "X" in the symbols has the values 1 thru "total number."

Table 3.6-11. Dynamic Control Input to the Lower Level Supervisor

Symbol	Total Number	Type	Description
REV	1	logical	During reversal, the dynamic control is in the active mode (logical 1).

Table 3.6-12. Upper Level Supervisor Inputs to the Lower Level Supervisor

Symbol	Total Number	Type	Description
(A) A_{g1} A_{g2} A_{g3} A_{g4} A_{m1} A_{m2}	6	logical	Gives whether a machine is available (logical 1) or is not available (logical 0) for inclusion in the propulsion system.
HOLD	1	logical	Upper level supervisor is in the passive mode (logical 0) or active mode (logical 1).
$C_{old\ reset}$	1	discrete variable	Gives configuration when upper level supervisor changes from the active to the passive mode.
(SOPEN) SXOPEN	16	logical	Each parameter commands switch X to open (logical 1) or not to change position (logical 0)

Table 3.6-13. Lower Level Supervisor Inputs to the Switch Controls

Symbol	Total Number	Type	Description
(S_r) SX_r	16	logical	Each reference commands switch X to be open (logical 0) or closed (logical 1).

Table 3.6-14. Lower Level Supervisor Inputs to the Turbine Controls

Symbol	Total Number	Type	Description
(N_r)	4	variable	
N_{r1}			Turbine 1 speed reference
N_{r2}			Turbine 2 speed reference
N_{r3}			Turbine 3 speed reference
N_{r4}			Turbine 4 speed reference

Table 3.6-15. Lower Level Supervisor Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
C_{old}	1	discrete variable	Gives the configuration in which the system is operating. During transition, C_{old} has the value "NC."
(ERL)	6	variable	Field commands
ERL_{g1}			
ERL_{g2}			
ERL_{g3}			
ERL_{g4}			
ERL_{m1}			
ERL_{m2}			

Table 3.6-10 lists the 32 sensor signals which are also used directly as feedback signals by the lower level supervisor. The 16 switch signals are logical 0 in the open position and logical 1 in the closed position.

Table 3.6-11 shows the dynamic control input parameter REV. When a reversal is in progress, REV is true and the lower level supervisor is inhibited from performing a transition.

Table 3.6-12 lists the upper level supervisory control inputs. Six availability signals which correspond to the six SEGMAG machines indicate whether or not each is available for inclusion in the propulsion system. This information is used by the logic which controls the propulsion system configuration.

Whenever the upper level supervisor is in the active mode, the logical parameter HOLD is true which, among other things, places the switch commands under the dictates of the upper level supervisor. The parameter $C_{old\ reset}$ gives the configuration the propulsion system is in when the upper level supervisor returns to the passive mode.

Each of the sixteen SOPEN parameters commands a switch to open when true, otherwise the switch position is not altered.

Table 3.6-13 shows the sixteen switch reference commands, S_r, which correspond to the switches S1 through S16. These signals are input to the switch controls. When true, a switch is commanded to be closed, when false, a switch is commanded to be open.

Table 3.6-14 shows the four turbine speed reference signals which are input to the turbine controls. With minor exceptions, each signal reflects the optimum speed, i.e. the speed at which the gas turbine specific fuel consumption is minimized.

Table 3.6-15 lists the inputs to the dynamic control section. The discrete variable C_{old} has the value "NC" during transition. Otherwise

it indicates which configuration the system is operating in. Six field commands are also input to the dynamic control. These signals are only input to the exciter controls during transition.

3.6.3.3 Block Diagram

Following a brief explanation of the roll played by each of the four blocks in the lower level supervisory control section (Figure 3.6-14), a detailed description of the internal functioning of each is given.

In the passive mode, the CONFIG CONTROL block compares the operator selected configuration with the configuration the system is operating in. If these differ and the required machines are available, the configuration control triggers a transition and determines the new configuration in accordance with Figure 2.3-5. For instance, if the system were in the idle configuration with all six machines available and the operator then selected the full power configuration, the following would occur. The configuration control would first call for a change to the zero power configuration. After this transition had been completed, it would next trigger a change to the half power configuration, and then finally a change to the full power configuration.

As a final note, if a reversal is in progress, the configuration control is inhibited from calling for a transition.

The TRANSITION block contains fixed programs which perform configuration changes when triggered by the configuration control. During transition, these programs control the machine fields and change switch positions. When not performing a transition, the sixteen switch reference signals, $S1L_r$, $S2L_r$,...$S16L_r$, are held static with one of two values, logical 0 or logical 1.

The SWITCH COMMAND OVERRIDE block contains the logic which allows the upper level supervisory control to override the switch reference signals from the TRANSITION block.

The TURBINE SPEED REF block generates the four speed reference signals which are input to the turbine controls.

3.6.3.3.1 CONFIG CONTROL Block

Figure 3.6-15 shows a control diagram for the CONFIG CONTROL block. From the console, the operator selects the value of C_S which corresponds to one of four configurations: idle, quarter power, half power, or full power.

The parameter C_{max} gives the maximum power configuration attainable based upon the availability of the four generators. C_{max} may have one of four values, 0, 1, 2, and 4, which correspond to the idle, quarter power, half power, and full power configurations.

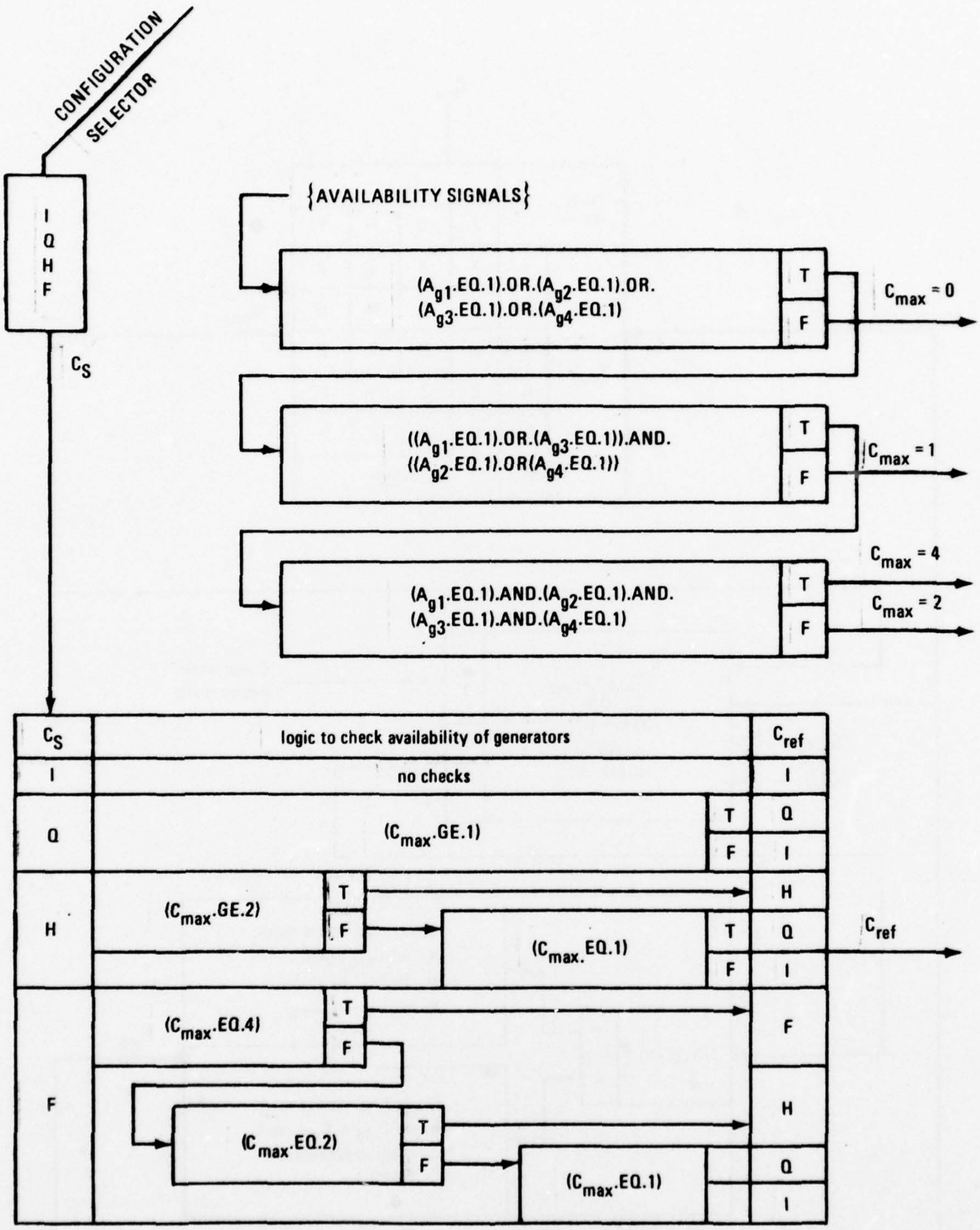


Figure 3.6-15a Configuration Control Diagram

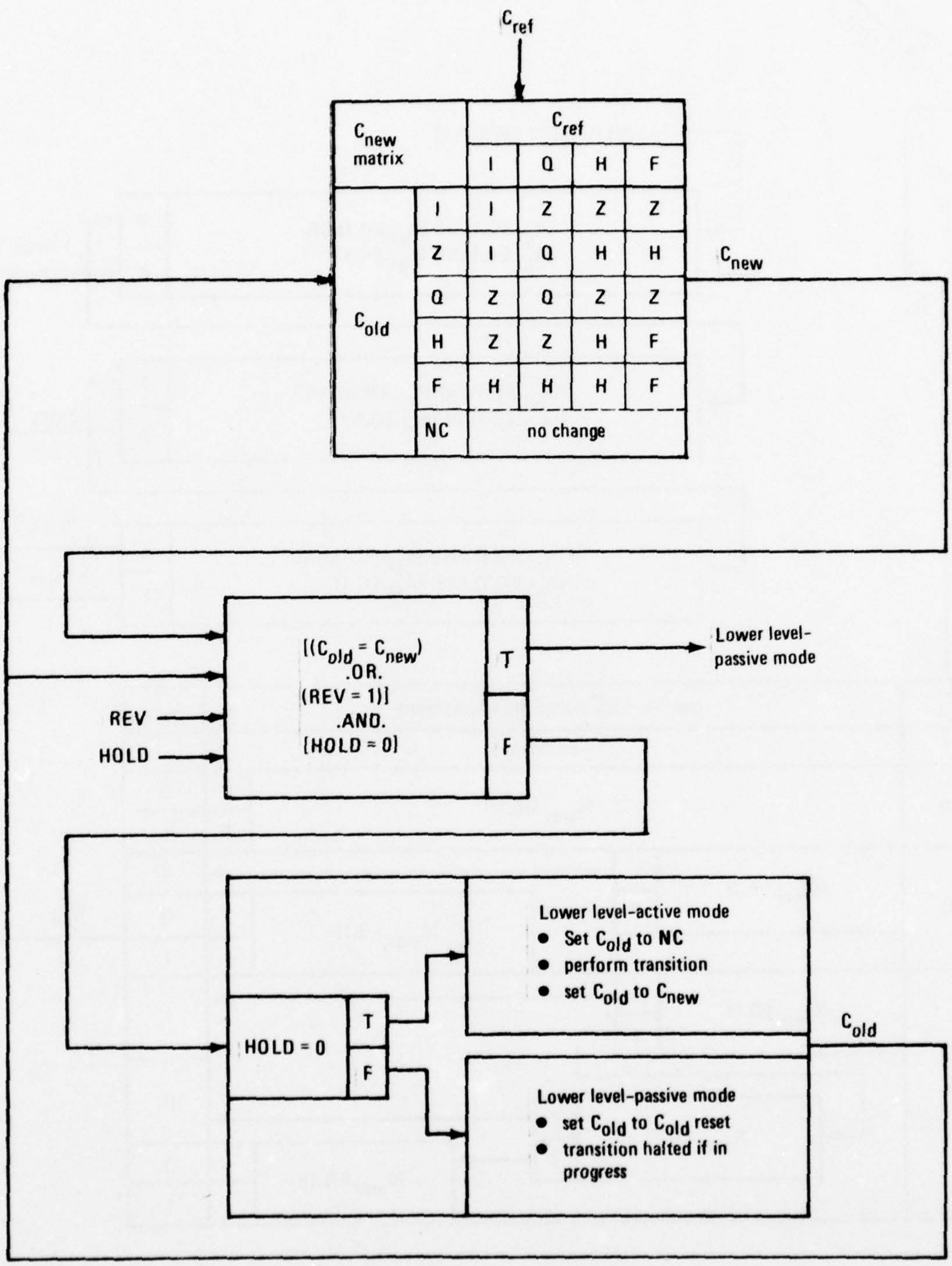


Figure 3.6-15b Configuration Control Diagram

The configuration reference parameter, C_{ref}, is set equal to the operator selected configuration if sufficient generators are available. If this is not the case, then the value of C_{max} is used.

The value of C_{new} is a function of the parameters C_{ref} and C_{old} as given by the C_{new} matrix. As long as C_{ref} and C_{old} are equal, C_{new} is also of the same value and the lower level supervisory control remains in the passive mode.

If C_{ref} changes to a new value, C_{new} gives the configuration to which the system should be changed in accordance with Figure 2.3-5. If a reversal is not in progress (REV false), a transition is performed during which time C_{old} is set equal to NC.

Whenever the upper level supervisory control is in the active mode, HOLD is true and C_{old} is set equal to $C_{old\ reset}$. Furthermore, if a transition were in progress, it would be terminated since the upper level supervisor takes over all field and switch commands.

3.6.3.3.2 TRANSITION Block

In carrying out a configuration change, a sequence of steps are taken, whereby certain conditions must be fulfilled before proceeding to the next step. The control system performs transitions by executing the appropriate built in program.

In the ensuing figures, a typical configuration change is given in outline form for each of the eight basic transitions.

Figure 3.6-16 shows a typical transition from the full power configration to the half power configuration. For the sake of brevity, only side 1 is illustrated, since the change on side 2 would be more or less a mirror image of the side 1 changes. For this example, it is assumed that generator 3 is taken off the line which of course is not necessarily the case. In actual operation, it could just as well be that generator 1 would be disconnected electrically from the propulsion system.

The initial conditions are highlighted, i.e. the conditions prior to performing the transition. Both of the parameters C_{new} and C_{old} are equal to F (full power configuration). The switch positions on side 1 are given as well as the make up of the field commands which are controlled by the dynamic control section.

Step 1 is initiated when C_{new} is changed to H. Subsequently C_{old} is changed to NC and the exciter control inputs then originate in the lower level supervisory control. The make up of the error signals for generator 1 and motor 1 are left unaltered, however, the error signal for generator 3 is changed so as to cause this generator to produce (approximately) zero current.

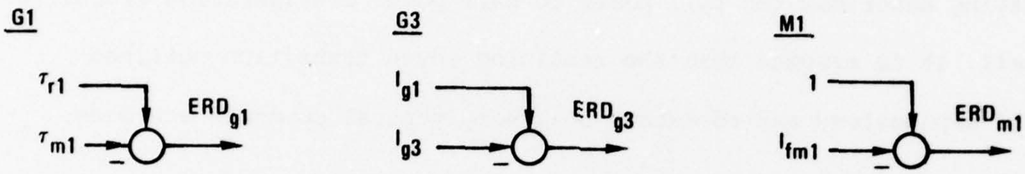
Step 2 is initiated when the absolute value of generator three's armature current is less than 0.01 p.u. (75 A). At this point, the reference signals for switches 3 and 7 are changed to logical 0 which commands these switches to open.

Step 3 is initiated when the feedback parameters S3 and S7 indicate that these switches are open. The make up of the error signal for generator 3 is changed such that the field current is controlled to be zero.

Side 1 G1, G3, M1 on line $\xrightarrow{\text{transition}}$ G1, M1 on line
G3 off line

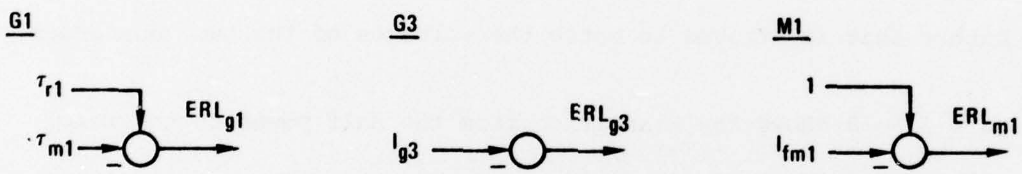
INITIAL CONDITIONS

- C_{new} = F, C_{old} = F
- Switch positions: 1, 3, 5, 7, and 13 closed/9, 11, and 15 open



STEP 1

- Condition: C_{new} = H
- C_{old} changed to NC

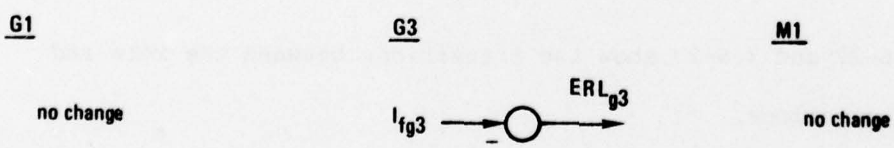


STEP 2

- Condition: $|I_{g3}| < 0.01$
- $S3L_r$ and $S7L_r$ changed from logical 1 to logical 0 (i.e. switches 3 and 7 are commanded to open)

STEP 3

- Conditions: S3 = 0 and S7 = 0 (i.e. switches 3 and 7 are open)



STEP 4

- Condition: G3 off line
- C_{old} changed to H

Figure 3.6-16 Transition, Full Power to Half Power Configuration

Step 4 is initiated when generator 3 is off line, i.e. when the change in the make up of the error signal for generator 3 is completed. C_{old} is changed to H and the transition is thus completed.

Having described the full power to half power configuration transition in detail, it is assumed that the remaining seven transition outlines are self explanatory and therefore only very general comments are made.

Figure 3.6-17 shows the transition from the half power to the full power configuration. Again, only side 1 is shown. Before paralleling generator 3 with generator 1, the field of generator 3 is controlled in such a manner that it strives to match the voltages of the two generators.

Figure 3.6-18 shows the transition from the half power to the zero power configuration and Figure 3.6-19 shows the reverse transition. Only side 1 is shown in the figures.

Figure 3.6-20 and 3.6-21 show the transitions between the zero and quarter power configurations. For these examples it is assumed that generator 1 is on line in the quarter power configuration.

Figures 3.6-22 and 3.6-23 show the transitions between the idle and zero power configurations.

3.6.3.3.3 SWITCH COMMAND OVERRIDE Block

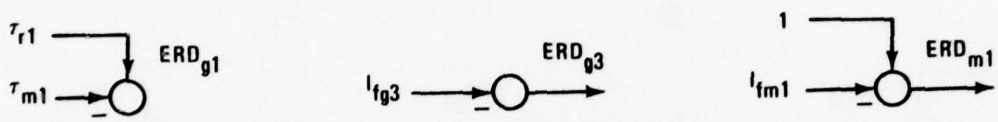
The logic for the SWITCH COMMAND OVERRIDE block is shown in Figure 3.6-24. The following description which uses switch 1 as an example applies equally to each of the 16 switches.

Side 1 G1, M1 on line $\xrightarrow{\text{transition}}$ G1, G3, M1 on line
G3 standby

INITIAL CONDITIONS

- C_{new} = H, C_{old} = H
- Switch positions: 1, 5, and 13 closed/3, 7, 9, 11, and 15 open

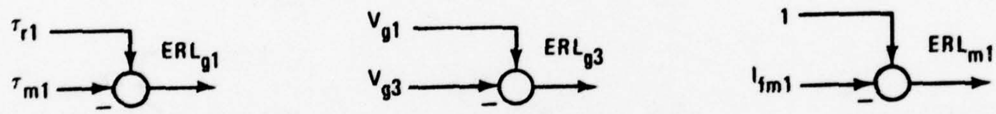
G1 G3 M1



STEP 1

- Condition: C_{new} = F
- C_{old} changed to NC

G1 G3 M1



STEP 2

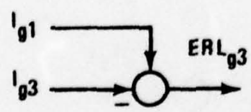
- Condition: $|V_{g1} - V_{g3}| < 0.01$
- $S3L_r$ and $S7L_r$ changed to logical 1

STEP 3

- Conditions: S3 and S7 = 1

G1 G3 M1

no change



no change

STEP 4

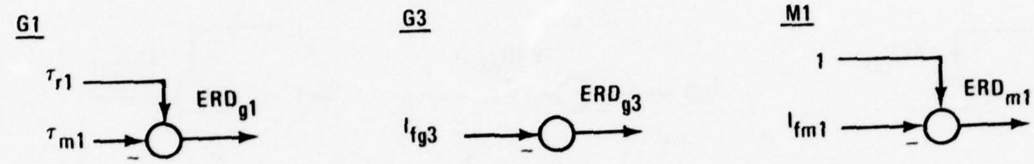
- Condition: *Change in makeup of error signal* ERL_{g3} completed
- Change C_{old} to H

Figure 3.6-17 Transition, Half Power to Full Power Configuration

Side 1 G1, M1 on line $\xrightarrow{\text{transition}}$ G1, G3, M1 off line
G3 off line

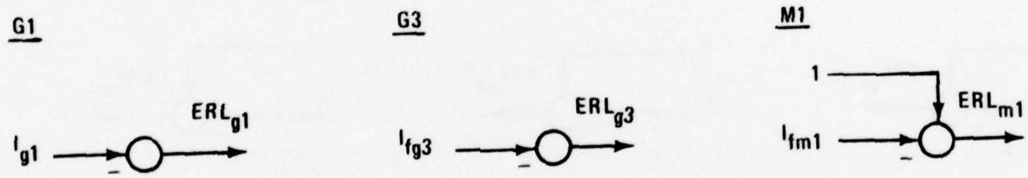
INITIAL CONDITIONS

- $C_{new} = H$, $C_{old} = H$
- Switch positions: 1, 5, and 13 closed/3, 7, 9, 11, and 15 open



STEP 1

- Condition: $C_{new} = Z$
- C_{old} changed to NC

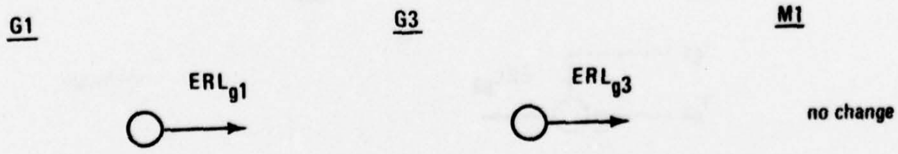


STEP 2

- Condition: $|I_{g1}| < 0.01$
- $S1L_r$, $S5L_r$, and $S13L_r$ changed to logical 0

STEP 3

- Conditions: S1, S5, and S13 = 0



STEP 4

- Conditions: Changes in makeup of error signals completed
- Change C_{old} to Z

Figure 3.6-18 Transition, Half Power to Zero Power Configuration

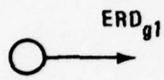
Side 1 G1, M1 standby $\xrightarrow{\text{transition}}$ G1, M1 on line

G3 off line G3 off line

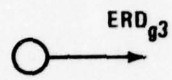
INITIAL CONDITIONS

- $C_{new} = Z$, $C_{old} = Z$
- Switch positions, 1, 3, 5, 7, 9, 11, 13, and 15 open

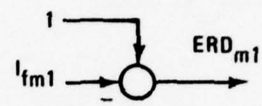
G1



G3



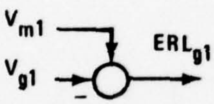
M1



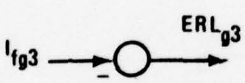
STEP 1

- Condition: $C_{new} = H$
- C_{old} changed to NC

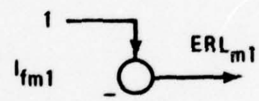
G1



G3



M1



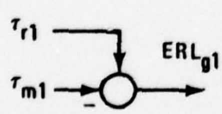
STEP 2

- Condition: $|V_{m1} - V_{g1}| < 0.01$
- $S1L_r$, $S5L_r$, and $S13L_r$ changed to logical 1

STEP 3

- Conditions: S1, S5, and S13 = 1

G1



G3

no change

M1

no change

STEP 4

- Condition: Change in makeup of error signal ERL_{g1} completed
- Change C_{old} to H

Figure 3.6-19 Transition, Zero Power to Half Power Configuration

G1, M1, M2 on line $\xrightarrow{\text{transition}}$ G1, M1, M2 off line

INITIAL CONDITIONS

- C_{new} = Q, C_{old} = Q
- Switch positions: 1, 5, 9, 12, 15, and 16 closed/2, 3, 4, 6, 7, 8, 10, 11, 13, and 14 open

G1

per Figure 3.6-8a

M1

per Figure 3.6-8b

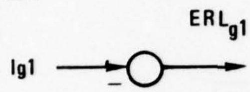
M2

per Figure 3.6-8b

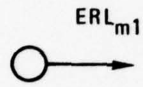
STEP 1

- Condition: C_{new} = Z
- C_{old} changed to NC

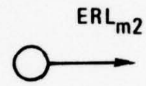
G1



M1



M2



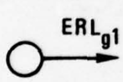
STEP 2

- Condition: $|Ig1| < 0.01$
- S1L_r, S5L_r, S9L_r, S12L_r, S15L_r, and S16L_r changed to logical 0

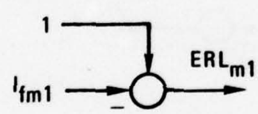
STEP 3

- Conditions: S1, S5, S9, S12, S15, and S16 = 0

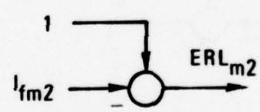
G1



M1



M2



STEP 4

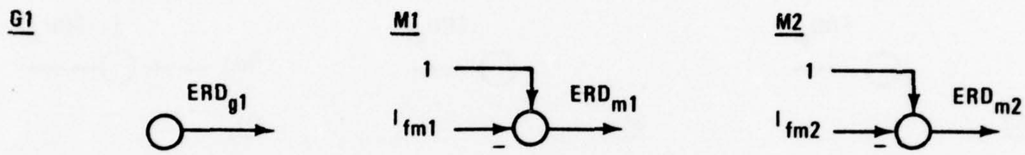
- Conditions: changes in makeup of error signals completed
- Change C_{old} to Z

Figure 3.6-20 Transition, Quarter Power to Zero Power Configuration

G1, M1, M2 standby $\xrightarrow{\text{transition}}$ G1, M1, M2 on line

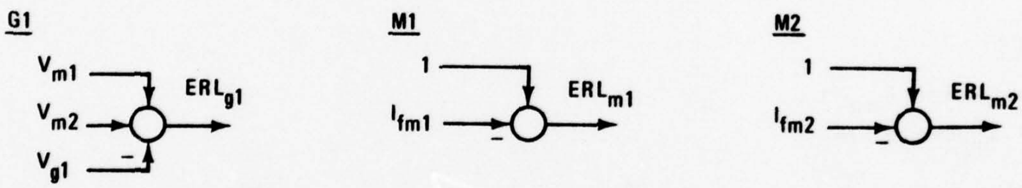
INITIAL CONDITIONS

- $C_{new} = Z$, $C_{old} = Z$
- Switch positions: all switches open



STEP 1

- Condition: $C_{new} = Q$
- C_{old} changed to NC



STEP 2

- Condition: $|V_{m1} + V_{m2} - V_{g1}| < 0.01$
- $S1L_r$, $S5L_r$, $S9L_r$, $S12L_r$, $S15L_r$, and $S16L_r$ changed to logical 1

STEP 3

- Conditions: S1, S5, S9, S12, S15, and S16 = 0

G1	M1	M2
per Figure 3.6-8a	per Figure 3.6-8b	per Figure 3.6-8b

STEP 4

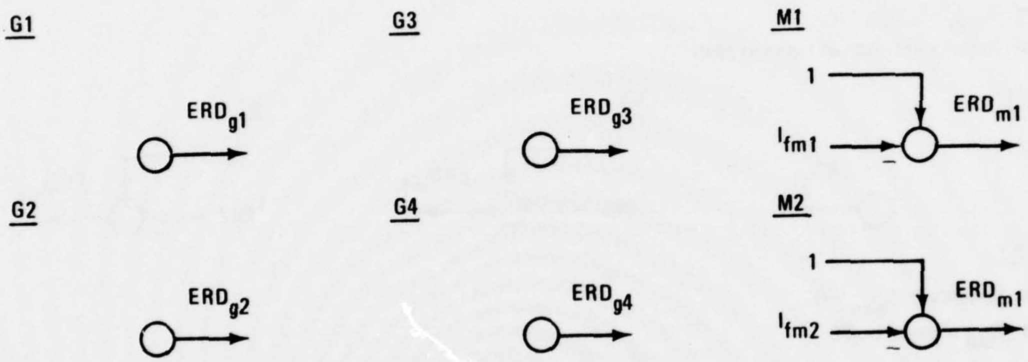
- Conditions: Change in makeup of error signals completed
- Change C_{old} to Q

Figure 3.6-21 Transition, Zero Power to Quarter Power Configuration

G1, G2, G3, G4, off line $\xrightarrow{\text{transition}}$ G1, G2, G3, G4, off line
M1, M2 M1, M2

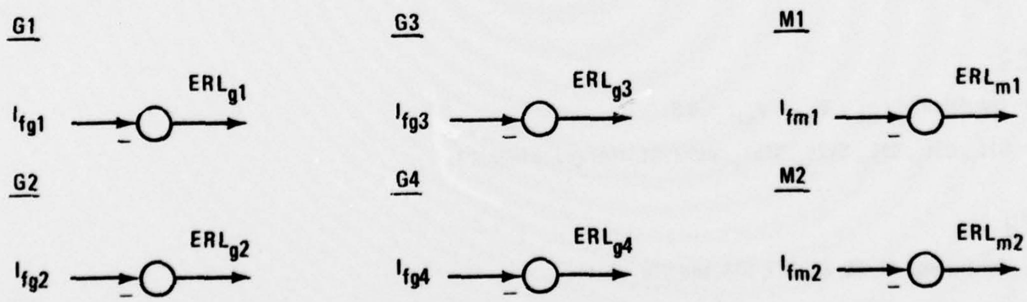
INITIAL CONDITIONS

- $C_{new} = Z$, $C_{old} = Z$
- Switch positions: all switches open



STEP 1

- Condition: $C_{new} = I$
- C_{old} changed to NC



STEP 2

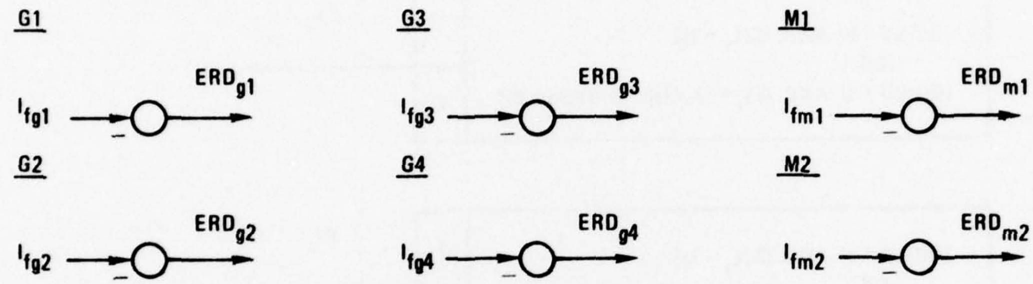
- Condition: Change in makeup of error signals completed
- Change C_{old} to I

Figure 3.6-22 Transition, Zero Power to Idle Power Configuration

G1, G2, G3, G4, off line $\xrightarrow{\text{transition}}$ G1, G2, G3, G4, off line
M1, M2   M1, M2

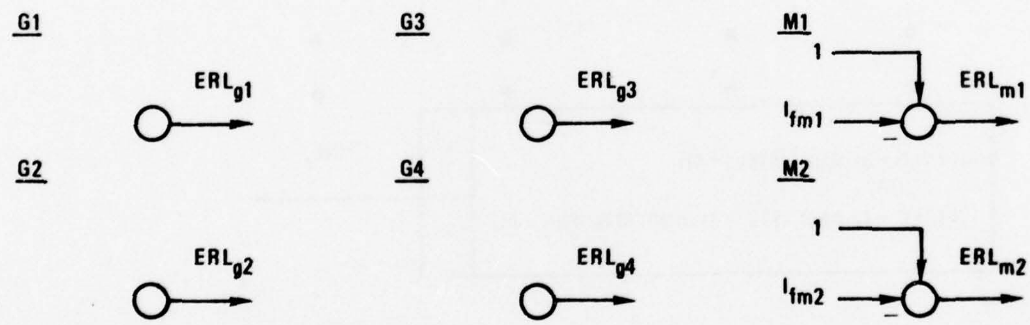
INITIAL CONDITIONS

- $C_{new} = I$, $C_{old} = I$
- Switch positions: all switches open



STEP 1

- Condition: $C_{new} = Z$
- C_{old} changed to NC



STEP 2

- Conditions: Changes in makeup of error signals completed

STEP 3

- Conditions: $I_{fm1} > 0.95$ and $I_{fm2} > 0.95$
- Change C_{old} to Z

Figure 3.6-23 Transition, Idle to Zero Power Configuration

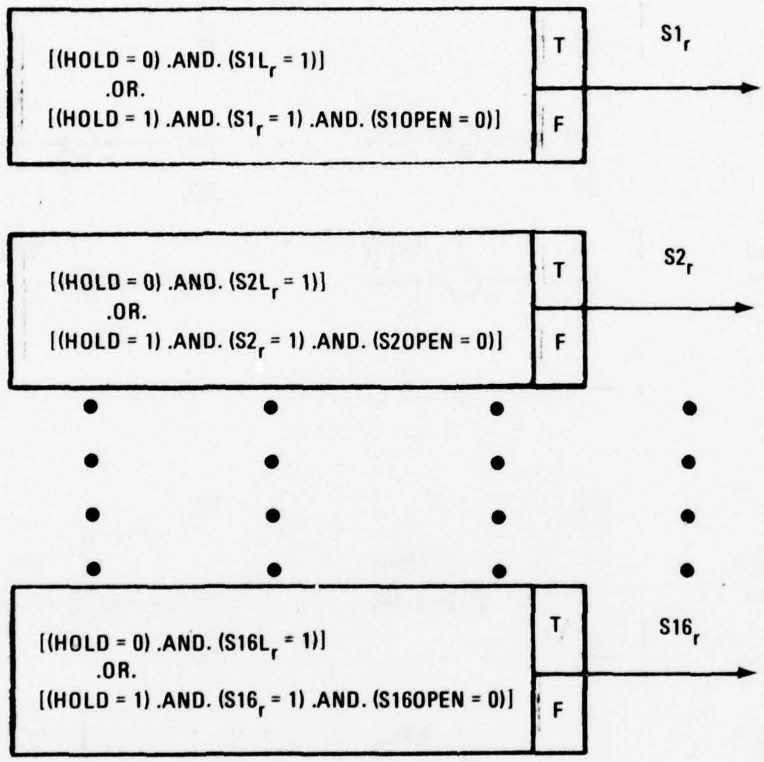


Figure 3.6-24 Switch Command Override Logic

When the upper level supervisory control section is in the passive mode (HOLD = 0), the switch reference command, $S1_r$, is equal to the reference generated by the lower level supervisor, $S1L_r$.

When the upper level supervisor is in the active mode, the parameter HOLD is true (logical 1). Two options are then available to the upper level supervisor. Either the switch reference command, $S1_r$, is left unchanged or, if it is true, switch 1 may be commanded to open by making S1OPEN true. Note that the upper level supervisor can not command an open switch to close since this capability is not needed in order to fulfill its tasks.

3.6.3.3.4 TURBINE SPEED REF Block

A turbine speed reference signal is generated for each turbine. Each of the four signals is input to the gas turbine controls which strive to match the power turbine speed with the reference speed by adjusting the turbine fuel flow rate. In the following, only the speed reference for turbine number 1 is described, the other three speed references being similar in make up.

Figure 3.6-25 illustrates the manner in which turbine speed reference 1 is generated. For the moment, assume that the generator field current, I_{fg1}, is within the range of $-\gamma_1$ to $+\gamma_1$ and thus the output of the top function block is 1 and the logic block below is false.

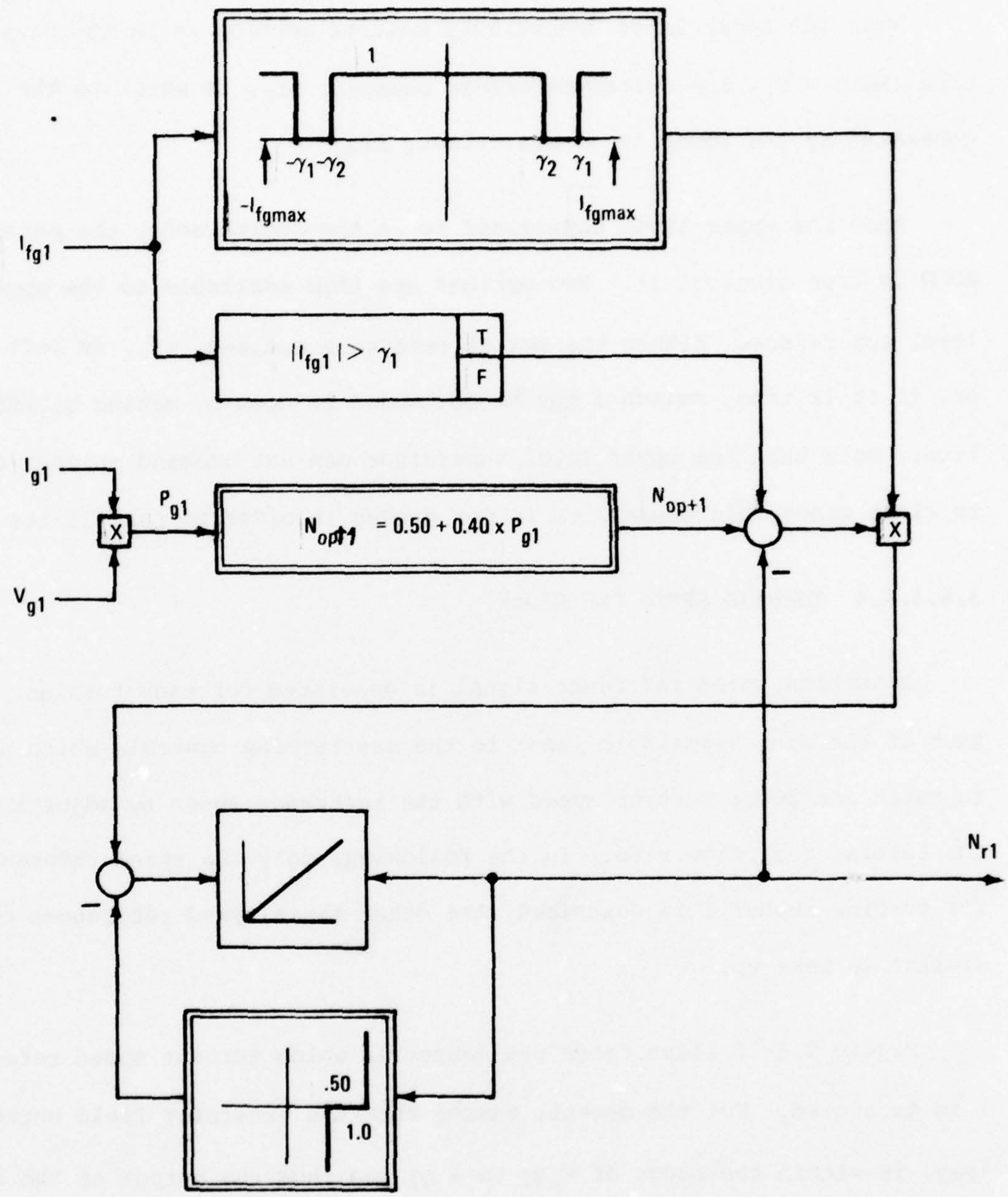


Figure 3.6-25 Turbine Speed Reference Control Diagram

As shown, the generator output power, P_{g1}, is calculated by taking the product of the generator current and generator voltage. From this, the optimum turbine speed, N_{opt1}, is determined. This represents the operating point at which the gas turbine specific fuel consumption is minimized.

At zero generator power output this is the approximate idle speed of the power turbine, 0.50 p.u. (1800 rev/min). At base operating conditions (P_{g1} = 1.0 p.u. = 15000 kW) this speed is 0.90 p.u. (3248 rev/min).

Now, the roll played by the top function block and the logic block below it will be discussed. It can happen that the generator becomes field current limited and therefore cannot meet its output requirements if turning at the optimum speed.

This can occur for instance when trying to parallel a generator on standby with one which is powering a motor at high power levels. At idle speed (1800 rev/min), the maximum generator voltage is about 1150 V. A generator operating in the half power configuration at rated power would produce power at 1584 V. In order to parallel machines under these conditions, it is necessary to increase the speed of the generator on standby above the optimum speed.

When the generator field current is greater than γ_1, the logic block is true which results in increasing the turbine reference speed. If, as the turbine accelerates, the generator output requirements are achieved, the generator field will start to decrease. For stability, a small dead

band between generator field values of γ_1 and γ_2 is incorporated, i.e. the speed reference is held constant whenever the generator field is within this range. As shown, this also holds for reversed generator fields. The values of γ_1 and γ_2 would be very close to I_{fgmax} which is the maximum attainable generator field current (approximately 1.15 p.u.).

3.6.4 Upper Level Supervisory Control

3.6.4.1 Functions

The most important functions performed by the upper level supervisory control are of the conditional rather than continuous type. In the passive mode, the propulsion system and control system including control console inputs are monitored for the occurrence of five categories of conditions which are anticipated to arise infrequently.

In the event that one of these conditions occurs, the upper level supervisor triggers a corresponding command. Once triggered, the upper level takes over control of the system (active mode) and performs a sequence of steps which result in the upper level returning to the passive mode and thus, returning control to the lower level supervisory and dynamic controls.

The following is a list of the five categories of conditions with a brief description of each.

<u>START</u>

The start command readies the propulsion system for operation. Every time the control system power is turned on, the starting sequence must be carried out before commencing with operation under the lower level supervisory and dynamic controls. During start, the proper initial values are given to the various controller logic signals. Also, it is insured that all switches are open.

STOP

The stop command provides for an orderly shut down of the propulsion system. At the end of the stopping sequence, all switches are open, the SEGMAG machine field currents are zero, and the gas turbines are commanded not to drive the SEGMAG generators.

On a routine basis, upon completing a mission the stop command would be given. After the sequence has been completed, the control system power may be turned off.

RESTART

The restart command interrupts the lower level supervisory and dynamic controls and places these controls and the propulsion system in the states they would have at the end of the starting sequence. The purpose of the restart cycle is to regain proper control in the event of a minor malfunction. This could be caused by such things as a transducer failure, an improbable operating condition that "locked-up" the lower level or dynamic control, etc.

EMER

Emergency conditions are any or all of the conditions which require immediate and rapid shut down of the propulsion system with the exception of electrical faults in the SEGMAG armature circuit(s). An emergency condition could be a machine overspeed, loss of lube oil pressure, etc. The emergency command immediately signals the gas turbine controls to

rapidly shut down the gas turbines. After a time delay, the emergency shut down sequence commands zero armature current, opens the switches, and deenergizes the SEGMAG machine fields.

The armature circuit is not broken immediately due to two reasons: 1) it places unnecessary stress on the components and 2) in some situations it could be undesirable (e.g. overspeed due to a sudden loss of load).

FAULT

The fault command simultaneously deenergizes the fields of the SEGMAG machines rapidly, and signals the gas turbine controls to quickly shutdown the gas turbines.

Any of the five commands described above may be activated by the operator from the control console. In monitoring the propulsion system, the upper level supervisory control activates the RESTART, EMER, or FAULT commands upon detecting the need to take corrective action. An important feature of the control system is that when the drive is in the split plant mode, the two sides are treated independently of one another.

In addition to the conditional control functions given above, the upper level supervisor also provides permissives to the gas turbine controls. In order for the gas turbines to be allowed to run, certain conditions must be met, e.g. the lube oil systems must be operating.

3.6.4.2 Input/Output

Figure 3.6-26 shows the upper level supervisory control input and output. Also shown is a simplified block diagram and the flow of most of the interconnecting signal paths is indicated. The blocks are described in the next section.

The input and output parameters are listed in tables 3.6-16 through 3.6-22. The symbol and total number for each parameter is shown. Also, the type of signal (i.e. logical, variable, etc.) and a brief description of each parameter is given.

Table 3.6-16 lists the eleven inputs from the console. These are all logical signals and except for the six permissive signals, they are activated by normally open (N.O., logical 0) push buttons. The $START_{con}$ and $STOP_{con}$ inputs to the upper level are used for startup and normal shutdown of the system.

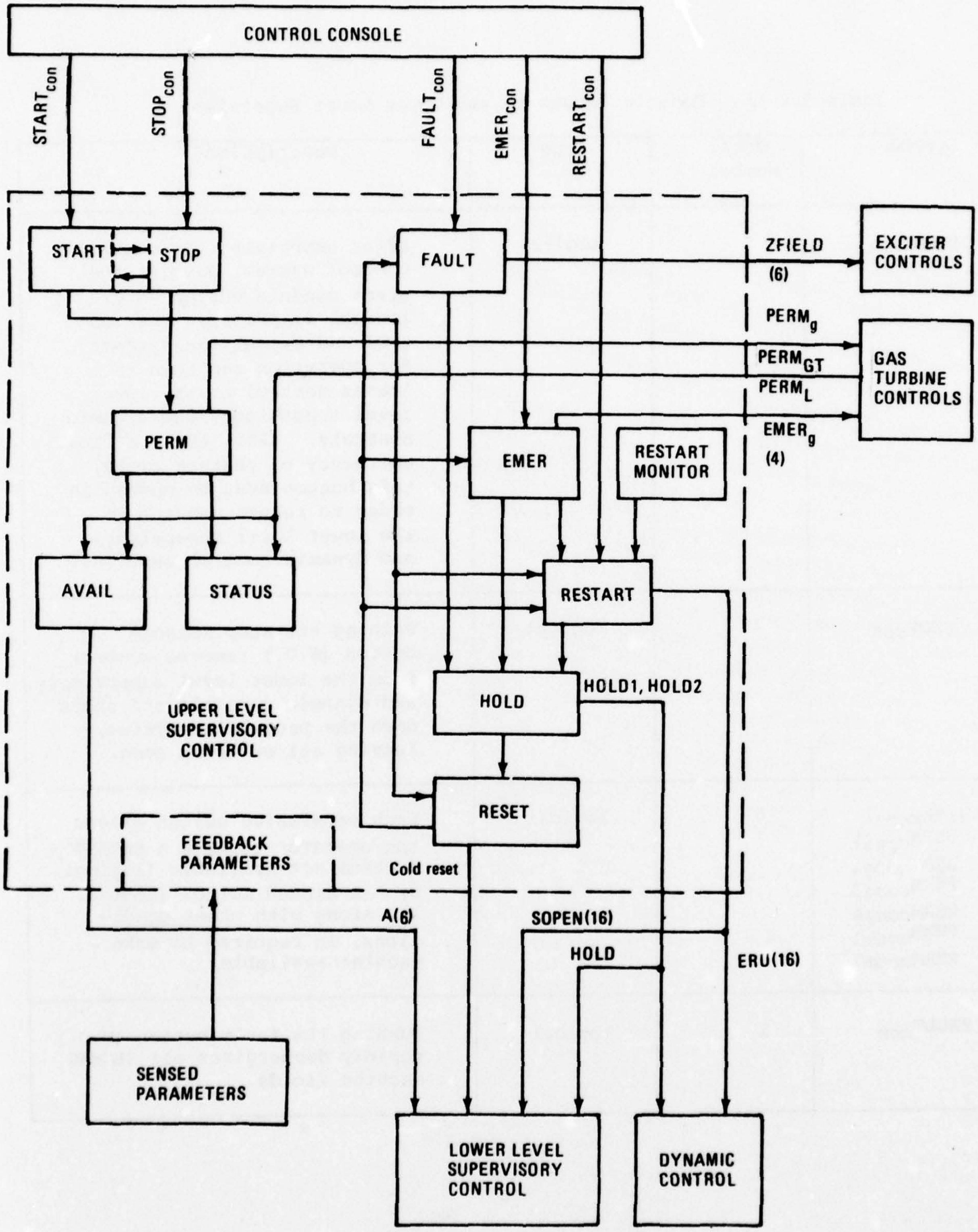


Figure 3.6-26 Upper Level Supervisory Control Input/Output and Block Diagram

Table 3.6-16. Console Inputs to the Upper Level Supervisor

Symbol	Total Number	Type	Description
$START_{con}$	1	logical	After energizing the control control system, pushing the start console button (N.O/ logical 0) prepares the control and propulsion systems for operation and then releases control to the lower level supervisory and dynamic controls. Also, after a fault, emergency or restart cycle, this button must be pushed in order to return control to the lower level supervisor and dynamic control sections.
$STOP_{con}$	1	logical	Pushing the stop console button (N.O.) removes control from the lower level supervisory and dynamic controls and shuts down the propulsion system, leaving all switches open.
($PERM_{con}$) $PERM_{cong1}$ $PERM_{cong2}$ $PERM_{cong3}$ $PERM_{cong4}$ $PERM_{conm1}$ $PERM_{conm2}$	6	logical	Each permissive switch allows the operator to make a SEGMAG machine not available (logical 0). A closed switch (logical 1), along with other conditions, is required to make a machine available.
$FAULT_{con}$	1	logical	Pushing the fault button (N.O.) rapidly deenergizes all SEGMAG machine fields.

Table 3.6-16. Console Inputs to the Upper Level Supervisor (Continued)

Symbol	Total Number	Type	Description
$EMER_{con}$	1	logical	Pushing the emergency button (N.O.) commands a rapid shut-down of the propulsion system, but does not quickly deenergize the fields.
$RESTART_{con}$	1	logical	Pushing the restart button (N.O.) places the system in the same state as at the end of the starting cycle (idle configuration)

Table 3.6-17. Upper Level Supervisor Inputs to the Exciter Controls

Symbol	Total Number	Type	Description
(ZFIELD) $ZFIELD_{g1}$ $ZFIELD_{g2}$ $ZFIELD_{g3}$ $ZFIELD_{g4}$ $ZFIELD_{m1}$ $ZFIELD_{m2}$	4	logical	When the zero field command is given (logical 1) to an exciter, the field is to be rapidly deenergized.

Table 3.6-18. Upper Level Supervisor Feedback Parameters

Symbol	Total Number	Type	Description
SX	16	logical	Switch-x position, open-logical 0/closed-logical 1
N_{gx}	4	variable	Generator-x speed
I_{gx}	4	variable	Generator-x current
N_{mx}	2	variable	Motor-x speed
I_{mx}	2	variable	Motor-x current
NMX	2	integer (2 value)	Motor-x rotational direction: positive is +1, negative is -1
OIL_{gx}	4	logical	Generator-x lube oil status (sufficient for operation, logical 1/insufficient, logical 0)
OIL_{mx}	2	logical	Motor-x lube oil status
$EXCIT_{gx}$	4	logical	Generator exciter-x is (logical 1) or is not (logical 0) energized
$EXCIT_{mx}$	2	logical	Motor exciter-x energized
$CO2_{gx}$	4	logical	Generator-x CO_2 system status
$CO2_{mx}$	2	logical	Motor-x CO_2 system status
$H2O_{gx}$	4	logical	Generator-x H_2O system status
$H2O_{mx}$	2	logical	Motor-x H_2O system status

Notes: 1) "X" in the symbols has the values 1 thru the "total number".

2) The first 30 symbols (SX thru I_{mx}) are sensor signals which are used directly as feedback parameters. The sensor signals and logic required for the last 24 feedback parameters (OIL_{gx} thru $H2O_{mx}$) are to be determined.

Table 3.6-19. Upper Level Supervisor Inputs to the Lower Level Supervisor

Symbol	Total Number	Type	Description
(A) A_{g1} A_{g2} A_{g3} A_{g4} A_{m1} A_{m2}	6	logical	Gives whether a machine is available (logical 1) or is not available (logical 0) for inclusion in the propulsion system.
HOLD	1	logical	Upper level supervisor is in the passive mode (logical 0) or active mode (logical 1).
$C_{old\ reset}$	1	discrete variable	Gives configuration when upper level supervisor changes from the active to the passive mode.
(SOPEN) SXOPEN	16	logical	Each parameter commands switch X to open (logical 1) or not to change position (logical 0)

Table 3.6-20. Upper Level Supervisor Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
HOLD1	1	logical	Upper level is in the passive mode (logical 0) or active mode (logical 1) with respect to side 1.
HOLD2	1	logical	Upper level is in the passive or active mode with respect to side 2.
(ERU) ERU_{g1} ERU_{g2} ERU_{g3} ERU_{g4} ERU_{m1} ERU_{m2}	6	variable	Field commands-only used when upper level is in the active mode.

Table 3.6-21. Upper Level Supervisor Inputs to the Gas Turbine Controls

Symbol	Total Number	Type	Description
($EMER_g$) $EMER_{g1}$ $EMER_{g2}$ $EMER_{g3}$ $EMER_{g4}$	4	logical	When the emergency command is given (logical 1), the appropriate gas turbine(s) is/are to be rapidly shut down.
($PERM_g$) $PERM_{g1}$ $PERM_{g2}$ $PERM_{g3}$ $PERM_{g4}$	4	logical	Each generator permissive informs the gas turbine controls if a generator may be driven (logical 1) or not (logical 0).

Table 3.6-22. Gas Turbine Control Inputs to the Upper Level Supervisor

Symbol	Total Number	Type	Description
($PERM_{GT}$) $PERM_{GT1}$ $PERM_{GT2}$ $PERM_{GT3}$ $PERM_{GT4}$	4	logical	Each gas turbine permissive informs the SEGMAG control system if a gas turbine is capable of driving a generator (logical 1) or not (logical 0).

A permissive switch is located at the console for each of the six SEGMAG machines. In the off position (logical 0) the machine is not allowed to be driven either mechanically by a gas turbine or electrically by other parts of the SEGMAG system. An on position (logical 1) is one of several conditions that must be met before a generator, or motor, may be operated as part of the propulsion system.

Part of the upper level control monitors pertinent propulsion system feedback parameters and upon sensing a condition requiring corrective action, a fault, emergency, or restart cycle is initiated automatically. As a backup, these same cycles may also be commanded by the operator by pushing the appropriate console button. At the end of any of these cycles all switches are open and the gas turbines are not allowed to drive the generators with the exception of operation in the half and full power configurations. When operating in these split plant modes it could well occur that only one side would be deenergized. After the cause of the condition requiring corrective action has subsided, the propulsion system continues to be inhibited from operating until the $START_{con}$ command is given by the operator at the console. Again, in the split plant mode it could well be that one side continues operation under the lower level supervisory and dynamic controls.

Table 3.6-17 lists the six exciter control inputs from the upper level which are activated under fault conditions. When ZFIELD is changed to logical 1, the field of the SEGMAG machine is to be rapidly deenergized.

Table 3.6-18 lists the 54 feedback parameters required by the upper level. The first 30 comprise the sensor signals for the switch positions, the machine rotational speeds, and the machine armature currents.

The next two feedback parameters, NM1 and NM2, give the motor rotational directions.

The last 24 feedback parameters are logical signals which are determined by monitoring the machine auxiliaries: The four parameters must be true (logical 1) for a machine to be available for inclusion in the propulsion system with the exception that the H_2O systems may be shut down in the idle configuration. The logic and sensor signals required to generate these feedback signals have yet to be determined.

Table 3.6-19 lists the lower level supervisor inputs from the upper level supervisor. Six availability signals which correspond to the six SEGMAG machines indicate whether or not each is available for inclusion in the propulsion system.

In the active mode, the parameter HOLD is true which places the switch commands under the dictates of the upper level supervisor. Thereby, the lower level supervisor temporarily looses track of the configuration. Upon reverting back to the passive mode, the parameter $C_{old\ reset}$ provides the information as to which configuration the propulsion system is in.

Each of the sixteen parameters, S1OPEN...S16OPEN, commands a switch to open when true, otherwise the switch position is not altered. The upper level supervisor does not have the means of commanding an open switch to close since this capability is not needed in order to fulfill its tasks.

Table 3.6-20 lists the upper level supervisor inputs to the dynamic control. The logical parameters HOLD1 and HOLD2 which apply to sides 1 and 2 respectively indicate if the upper level is in the passive or active mode.

The six field commands are only used as input to the exciter controls when the upper level is in the active mode.

Table 3.6-21 lists the upper level supervisor inputs to the gas turbine controls. The four emergency parameters, $EMER_{g1}...EMER_{g4}$, are normally logical 0. When a fault or emergency cycle is initiated, the emergency signals are changed to logical 1 and the result is to be a rapid shut down of the gas turbines.

The four permissive parameters, $PERM_{g1}...PERM_{g4}$, inform the gas turbine controls if a generator may be driven (logical 1) or not (logical 0). If while a generator is being driven its permissive signal is changed to logical 0, an orderly shutdown of the gas turbine is to result (as opposed to a rapid shut down).

Table 3.6-22 lists the four permissives from the gas turbine controls. They provide the upper level supervisor with the information of whether or not a gas turbine is prepared to drive a generator.

3.6.4.3 Block Diagram

This section discusses the roll that the various blocks in Figure 3.6-26 play and the interconnections between them. A detailed description of the internal functioning of each block will not be given, however, the prototype for this control system (i.e. the 3000 hp/shaft control system) is described fully in section ____.

When activated by the $START_{con}$ signal, the START/STOP block starts up the system primarily by initiating a restart cycle. Pushing the $STOP_{con}$ button shuts the system down in an orderly fashion by making all of the machine permissives false (logical 0). The START/STOP logic also generates a signal which provides the information of whether or not the propulsion system is operating in the split plant mode.

The PERM block generates a permissive signal for each SEGMAG generator and motor. In order for a permissive to be true, a number of conditions must be met e.g. lube oil sufficient for operation, exciter energized, etc.

The AVAIL block uses the permissives for the SEGMAG machines and the permissives from the gas turbine controls in order to determine the availability of each generator and motor.

The STATUS block generates a four valued signal for each machine which provides the information of whether the machine is off, ready (gas turbine not running), on standby (gas turbine at idle), or on line. The status signals are used by the fault, emergency, and restart monitor logic.

The FAULT block may be activated either by a console push button or by its own propulsion system monitoring logic. When activated, the machine fields are rapidly deenergized and the emergency and restart cycles are set in motion.

When activated, the EMER block sends signals ($EMER_g$) to the gas turbine controls which call for an emergency shut down of the gas turbines. After a time delay (5 seconds), the restart cycle is initiated.

The RESTART block provides for an orderly deenergization of the propulsion system. At the end of the cycle, all of the switches are open.

The HOLD block is activated whenever a fault, emergency, or restart cycle is set in motion. This block sends signals to the lower level supervisory and dynamic controls which has the effect of placing control under the upper level supervisor. The hold signals are also used as part of the permissive logic and reset logic.

The RESET block provides two signals, a reset signal and an updated value for C_{old} (i.e. $C_{old\ reset}$). In order to terminate a fault, emergency, or restart cycle, the reset signal must be made true. This can be done only when it is determined that the propulsion system is deenergized and when the operator pushes the start button on the console.

APPENDIX NO. 6

40,000 HORSEPOWER PER SHAFT DRIVE, CRASH-BACK
MANUEVER DIGITAL SIMULATION

6

Westinghouse Electric Corporation
Marine Division
Sunnyvale, CA

SEGMAG II Propulsion System for a Twin-screw Displacement Ship (40,000 hp/shaft)

Crash Back Maneuver Simulation (Digital)

Prepared by: R. Powell
March 23, 1978

CONTENTS

1. INTRODUCTION

An important aspect of the propulsion system is its crash back performance, i.e., the time it takes to stop the ship and the head reach. As an aid in investigating this maneuver for the destroyer type ship (40 khp/shaft), a digital computer simulation program was written which determines pertinent ship/propulsion system characteristics. Each crash back simulation case starts with the ship driving ahead under steady state operating conditions and ends with the ship dead in the water.

For each case, the crash back maneuver is broken down into the following phases:

Windmill Down

The motor torque is decreased to zero allowing the propeller speed to drop to the windmill speed.

Ship Shooting

The ship is allowed to shoot, i.e., the motor torque is zero and the propeller continues to windmill.

Reversal

The motor acts as a generator producing a negative torque which stalls the propeller.

Propeller Reversed

After stall, the motor drives the propeller in the reverse direction.

A total of 87 cases were investigated to determine the effect of the following variables upon the time to stop the ship, head reach, and energy generated during reversal:

1) time/ship speed at the start of reversal
2) motor torque during reversal
3) motor torque with the propeller reversed.

The crash back performance is primarily a function of two factors: 1) the maximum attainable motor torque, and 2) the energy absorbing capabilities of the propulsion system. The key part of the maneuver is the reversal phase where these two factors play a major role. To a lesser extent, the motor torque in the propeller reversed phase also has a considerable influence on the head reach and time to stop the ship.

A breakdown of the cases simulated is shown in Table 1-1. All three power configurations were investigated since the propulsion system crash back capabilities are different for each. Also, since the upper limit of the head reach and time to stop the ship are of most interest, all but six of the cases started the maneuver at the rated power point.

Table 1-1. Case Breakdown

No. of Cases	Power Configuration	Power* Point	Motor Torque During Reversal	Described in Section
18	Full	Full	Constant	4.1
13	Half	Half	Constant	4.2
12	Quarter	Quarter	Constant	4.3
3	Full	Half, Quarter, Cruise	Constant	4.4
2	Half	Quarter, Cruise	Constant	4.4
1	Quarter	Cruise	Constant	4.4
5	Full	Full	Ramp	5.
4	Half	Half	Ramp	5.
4	Quarter	Quarter	Ramp	5.
7	Full	Full	Saw-Tooth	6.1
5	Half	Half	Saw-Tooth	6.1
5	Quarter	Quarter	Saw-Tooth	6.1
4	Full	Full	Saw-Tooth, Weak Field	6.2
2	Half	Half	Saw-Tooth, Weak Field	6.2
2	Quarter	Quarter	Saw-Tooth, Weak Field	6.2

*At start of the maneuver

As indicated in the table, several different motor torque characteristics were simulated during the reversal phase. The constant torque cases are useful for study purposes. The ramp cases simulate the use of a mechanical brake and/or storing the energy in the turbine-generator rotating mass(es). The saw-tooth cases simulate the use of a dynamic resistor.

As the last part of this introduction, a few important points should be noted:

1) All calculations and values are on a half ship basis.

2) In many instances, the motor torque is given in percent which is always based upon the motor torque at the full power point (1.171×10^6 lb-ft.).

3) During the reversal and propeller reversed phases, the motor field current is always 1 p.u. except for the last eight cases (see Table 1-1) where the motor field is weakened during part of the reversal phase.

2. SYSTEM DESCRIPTION

2.1 Ship

The total ship displacement is 7800 tons which results in a mass for half the ship of 271,304 slugs. The drag on a half ship basis is given by the following formula, whereby the ship speed, V, is in ft/s:

$$F = \frac{183}{2} V^2, \text{ lb}$$

2.2 Propulsion System

Table 2-1 shows the steady-state operating conditions for each configuration when operated at their rated power points. For the purposes of simplifing the simulation, the motor losses are neglected and the motor torque is assumed to be proportional to the product of motor current and motor field current.

Table 2-1. Steady-State Operating Conditions

Power Configuration	Full	Half	Quarter
Ship speed (V), ft/s	54.01	42.87	34.02
Drag (F), lb	266,913	168,162	105,898
Propeller speed (N), rpm	168	133.3	105.8
Propeller torque (Qp), lb-ft	1.171×10^6	0.738×10^6	0.465×10^6
Motor torque (Qm), lb-ft	1.171×10^6	0.738×10^6	0.465×10^6
, %	100.0	63.0	39.7
Motor power (Pm), hp	37444	18722	9361
Motor current (Im), A	15000	9454	7500
Motor field current (I_{fm}), p.u.	1.0	1.0	0.79

In the propeller reversed phase of the of the crash back maneuver, the motor power is limited to the values shown in the above table.

During non steady-state operation, the difference between the motor torque and propeller torque accelerates the propeller-shaft-rotor which has a moment of inertia of 54,300 lb-ft-sec^2.

In the quarter power configuration, the motor field current is less than 1 p.u. at rated conditions. During the windmill down phase of the crash-back maneuver, the motor speed drops and the motor field is increased to 1 p.u. without exceeding the generator voltage limitation of 2000V.

Using the following component current ratings:

motor current (rated) = 15,000 A

generator current (rated) = 9,500 A

the maximum motor torque is established by limiting the motor and generator currents to 150 percent of their rated values. As shown in Table 2-2, the limiting machine is the motor in the full power configuration. In the other two configurations, the generator is the limiting factor.

Table 2-2. Component Currents at Maximum Motor Torque

Power Configuration	Full	Half	Quarter
Motor torque, % (lb-ft)	150 (1.756×10^6)	95 (1.112×10^6)	95 (1.112×10^6)
Motor current, % (A)	150 (22500)	95 (14250)	95 (14250)
Motor field current, p.u.	1.0	1.0	1.0
Generator current, % (A)	118 (11250)	150 (14250)	150 (14250)

During the propeller reversal phase, the energy generated by the motor may be dissipated in a mechanical brake (or dynamic resistor) and/or it may be stored in the rotating mass(es) of the T-G (turbine-generator) set(s). In those cases which involve stored energy, the following comments apply:

- The energy is stored only in those T-G sets which are operating in the system. Thus, on a half ship basis, there are 2, 1 and 0.5 T-G sets available for the full, half, and quarter power configurations respectively.

- The power turbine-generator rotor moment of inertia is estimated to be 104.8 lb-ft-sec^2.

- The generator and power turbine are both considered to be lossless.

- The speed at the beginning of the reversal phase is assumed to be 1800 rpm.

2.3 Propeller

The propeller characteristics are taken from NSRDC-Miniovich Data for propeller number 18. This data consists of two sets of tabulations. One gives values of the thrust coefficient, C_T, and the other the torque coefficient C_Q, as functions of the first angle-of-advance coefficient, θ. For given operating conditions, the propeller characteristics are determined by the following relationships:

first angle-of-advance coefficient

$$\theta = \tan^{-1}\left[\frac{V}{nD}\right]$$

torque equation

$$Q_P = \rho D^3 C_Q \left[V^2+(nD)^2\right] \text{ lb-ft}$$

thrust equation

$$T = \rho D^2 C_T \left[V^2+(nD)^2\right] \text{ lb}$$

whereby,

- n - propeller speed (rps)
- V - ship speed (ft/s)
- D - propeller diameter (ft)
- ρ - mass density of sea water ($slug/ft^3$)

The propeller diameter is set at 16.2 feet so that the propeller thrust equals the ship drag at the design point (i.e. 168 rpm propeller speed at a ship speed of 32 knots).

Figure 2-1 shows the propeller torque-speed characteristics for a range of ship speeds. Also shown is the steady state operating curve along which the propeller thrust equals the ship drag.

2.4 Propeller Reversal Capabilities

When reversing the propeller, the propeller torque increases negatively in an approximately linear fashion with decreasing propeller speed, reaching a peak absolute value near 4 rpm. The absolute value of the maximum propeller torque in percent of rated motor torque (100%= 1.171×10^6 lb-ft) is shown plotted against ship speed in Figure 2-2.

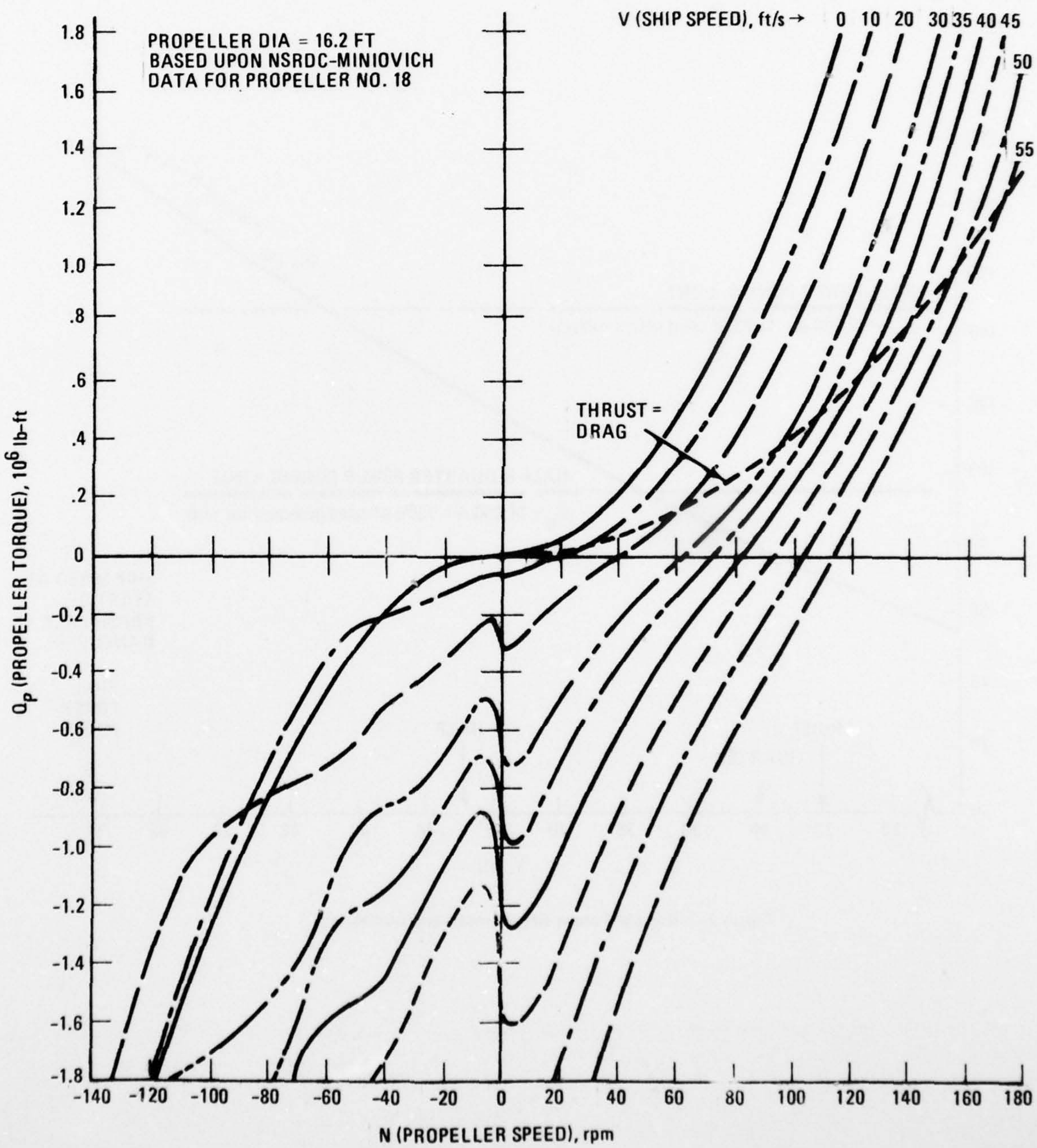


Figure 2-1 Propeller Characteristics

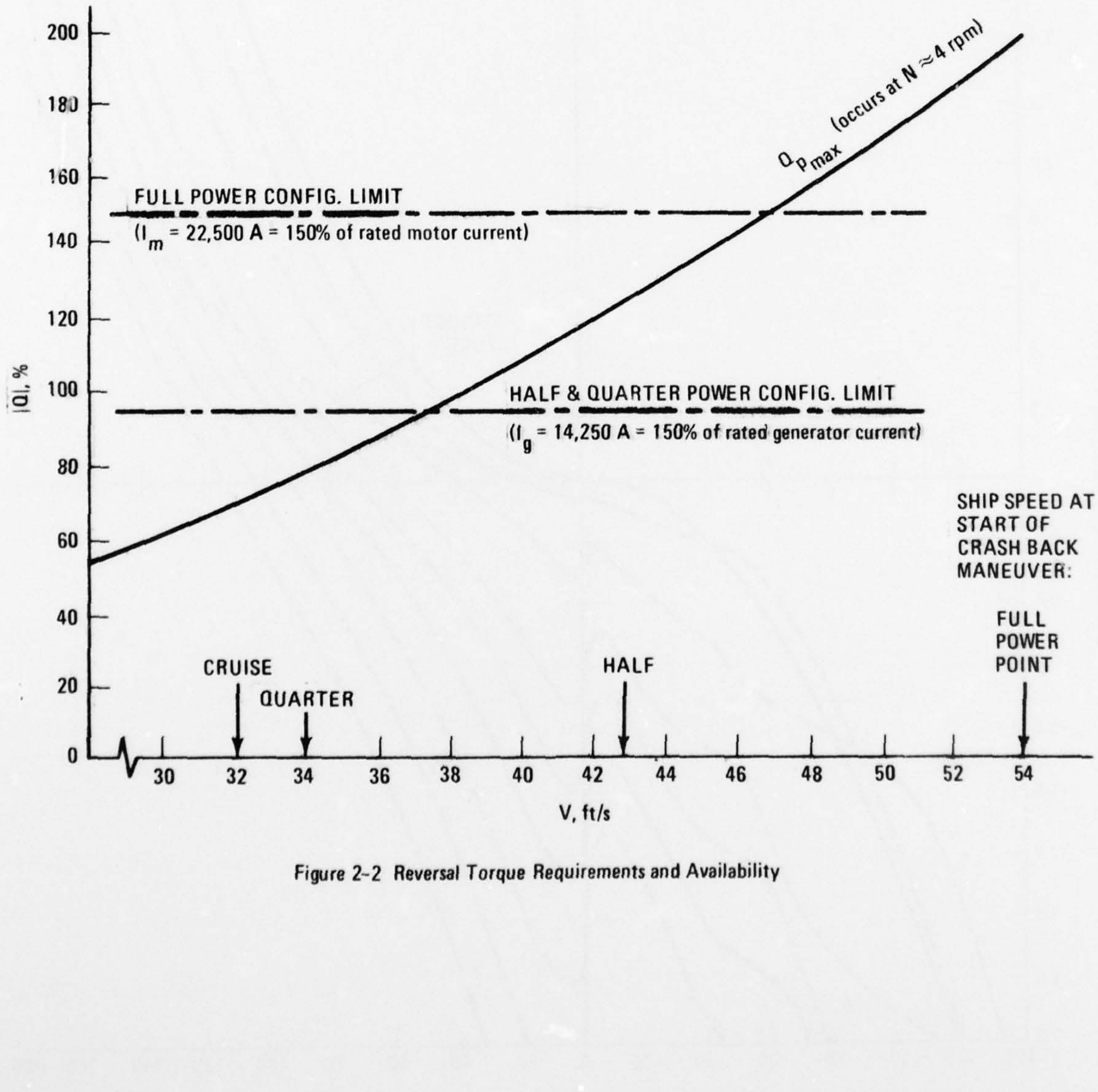


Figure 2-2 Reversal Torque Requirements and Availability

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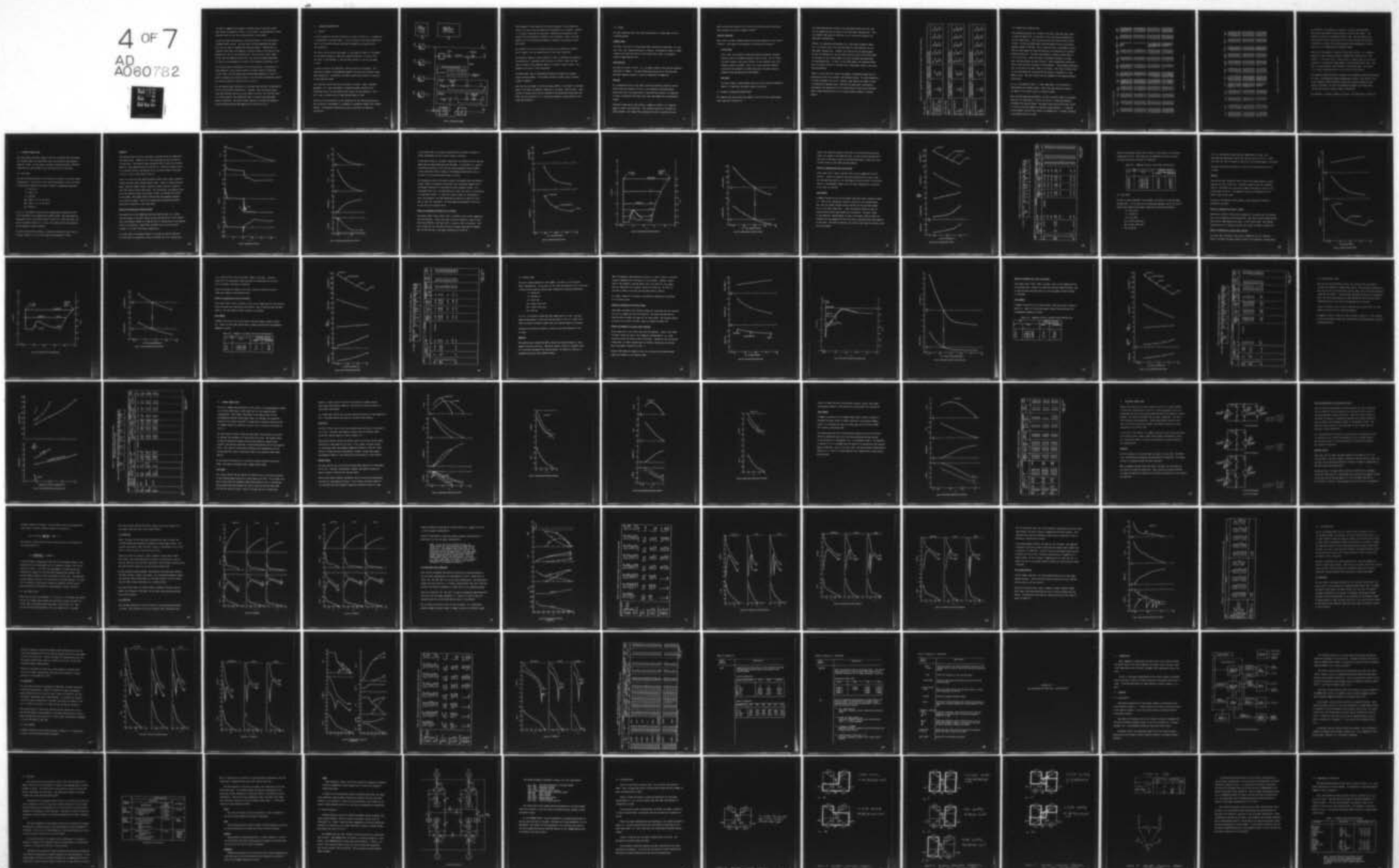

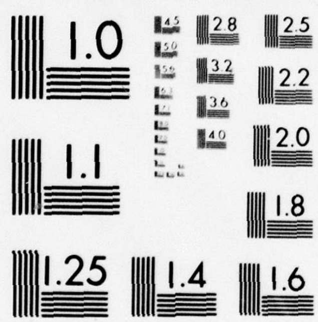

MICROCOPY RESOLUTION TEST CHART
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In order to complete the propeller reversal process, the motor torque must exceed the propeller torque. In the figure, the maximum motor torque absolute value for the three configurations is also shown.

In the full power configuration, the limiting factor is the 150 percent allowable motor current. At this limit, the ship speed must be below 46.9 ft/s in order to complete the reversal process. Simulations are reported herein where the propeller reversal process is initiated at ship speeds of 35, 40, 42, 45, and 46.9 ft/s. For this last initial speed, by the time the propeller nears stall, the ship has slowed sufficiently to result in an acceptable net torque on the propeller-shaft-motor rotor.

For the half power configuration, the limiting factor is 150 percent of rated generator current which results in a motor torque of 95 percent. At this limit, the ship speed must be below approximately 37.3 ft/s in order to complete the reversal process. The half power simulations started the reversal process at speeds of 32 to 38 ft/s.

For the quarter power configuration, the same limiting motor torque applies as for the half power configuration. However, since the quarter power crash back maneuver starts at a ship speed of 34 ft/s, the limiting factor is to allow time for the windmilling down (3 seconds) plus some small amount of shooting. The quarter power simulations started the propeller reversal process between ship speeds of 27 ft/s and 33 ft/s.

3. SIMULATION DESCRIPTION

3.1 Method

A block diagram of the basic simulation is shown in Figure 3-1. A simulation is influenced in two basic ways: 1) by the choice of the initial conditions and 2) by the control option which may be changed at any point during the simulation.

The choice of the initial ship speed, V, and propeller speed, N, correspond to the operating point at which the crashback maneuver is to start from. The time, t, the distance, s, and the motor energy, U, are all set equal to zero.

In order to control the simulation, several options are available. The time rate of change of the propeller speed or the value of the motor torque may be specified. In addition, the motor torque may be given as a function of the propeller speed.

The simulation starts with the first option in effect. When a selected parameter (i.e. time, ship speed, or propeller speed) achieves a predetermined value, the next option takes control of the simulation. For a given case, as many as six or eight options might be used.

The heart of the simulation is the integration of the time derivatives for the variables V (ship speed), s (distance), N (propeller speed), and U (motor energy). A Runga-Kutta subroutine was used to perform the numerical integration.

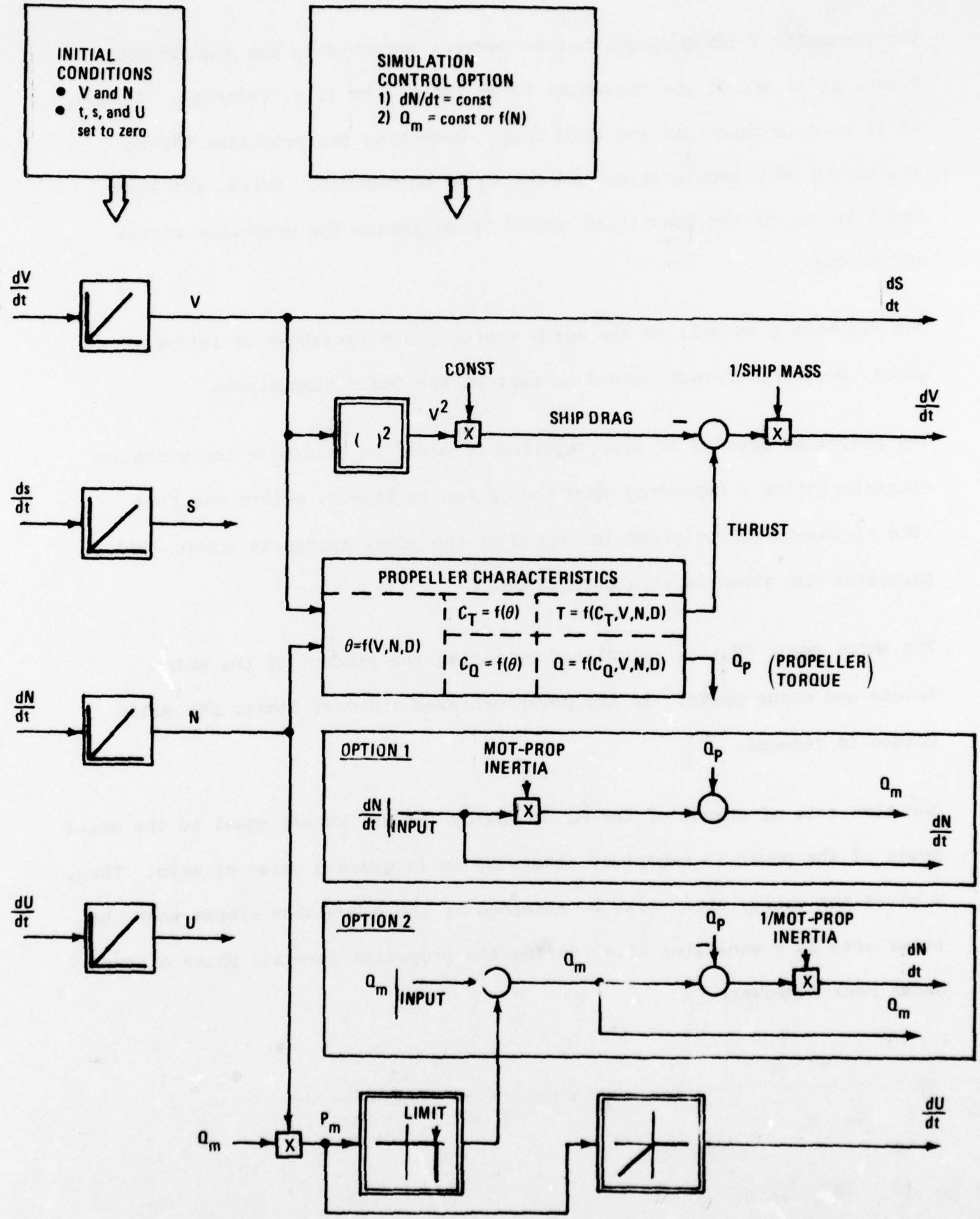


Figure 3-1 Simulation Block Diagram

The parameter V (ship speed) serves several purposes in the simulation. First, it is one of the variables to be integrated (i.e. $V=ds/dt$). Second, it is used to calculate the ship drag. Deducting the propeller thrust allows the ship acceleration (dV/dt) to be calculated. Third, the ship speed is one of the quantities needed to determine the propeller thrust and torque.

The distance s as well as the motor energy U are variables of interest which, however, are not needed as part of the basic simulation.

The propeller speed N is also required in order to determine the propeller characteristics. Depending upon the option in effect, either the time rate of change of the propeller speed or the motor torque is given. The parameter not given is then calculated.

The motor power (P_M) is calculated by taking the product of the motor torque and motor speed. If the power achieves a preset limit, the motor torque is reduced.

The time rate of change of the motor energy (dU/dt) is set equal to the motor power if the power is negative, otherwise it is given a value of zero. Thus, U gives the energy which must be absorbed by the propulsion system when the motor acts as a generator (i.e. during the propeller reversal phase of the crash back maneuver).

3.2 Phases

For each simulation case, the crash back maneuver is broken down into the following phases:

<u>Windmill Down</u>

Initially, the ship is driving ahead under steady-state conditions. At time zero (t=0), the crashback maneuver is started. The propeller speed is ramped linearly with time such that at three second after start, the propeller torque is approximately zero.

<u>Ship Shooting</u>

The ship is allowed to shoot, i.e., the motor torque is zero and the propeller continues to windmill. The ship decelerates mostly due to the ship drag. The small negative propeller thrust is neglegible by comparison.

<u>Reversal</u>

At a preselected time or ship speed, the motor produces a negative torque which brings the propeller to stall (zero propeller rotational speed). During this time, the energy which is generated by the motor is integrated in order to determine the energy abso bing requirements for the propulsion system.

The motor torque may be held constant, ramped as a function of propeller speed, or have a saw-tooth form. The constant torque case is useful for study purposes. The ramped case simulates the use of a mechanical brake

and/or storing the energy in the T-G set rotating mass and the saw-tooth case simulates the use of a dynamic resistor.

Propeller Reversed

After stall, the motor absorbes power driving the propeller in the reverse direction. This phase of the maneuver is divided into two parts:

Initial Part

After stall, the propeller torque dips sharply achieving a minimum absolute value at a propeller speed of about -8 rpm. For all cases, the motor torque at the end of reversal is held constant until this propeller speed is reached. This is to insure continued negative rotation of the propeller in those cases where the motor torque is reduced during the main part of this phase.

Main Part

The motor torque is held constant from the time at which the propeller speed is -8 rpm until the ship is dead in the water.

3.3 Windmill and Shooting Phase Values

The comments and values given here apply to all but the six reduced power cases reported in section 4.4.

The crash back maneuver starts at the rated power point and, thus, the initial conditions are the same for any given power configuration. Also, the windmill down phase is identical for all cases which simulate the same power configuration.

Further, the system characteristics (i.e. ship speed, propeller speed, etc.) at a given time in the shooting phase are also identical for the same power configuration. However, the duration of the shooting phase may well be different for any two cases since the value of the ship speed at the start of the reversal phase is one of the major variables which is investigated here. In fact, as one would expect, the time/ship speed point at which reversal is initiated has a significant effect on the crash back performance.

Table 3-1 lists the time, reach, ship speed, and propeller speed for the beginning and end of the windmill and shooting phases. The case designators are used throughout this study. However, dash numbers are added in order to differentiate between cases simulating the same power configuration and speed at the beginning of the reversal phase, but which have different motor torque characteristics in the reversal and/or propeller reversed phases.

Table 3-1. System Characteristics for the Windmill and Shooting Phases

Full Power Cases

Phase	Initial Conditions/ Windmill-Start	Windmill-End/ Shooting-Start	Shooting-End/ Reversal-Start				
Case Designation			F47	F45	F42	F40	F35
t (time), s	0	3.00	9.55	12.10	16.60	19.98	30.10
s (reach), ft	0	161	486	603	798	937	1315
V (ship sp), ft/s	54.0	52.6	46.9	45.0	42.0	40.0	35.0
N (prop sp), rpm	168.0	115.0	97.9	94.0	87.7	83.5	73.1

Half Power Cases

Phase	Initial Conditions/ Windmill-Start	Windmill-End/ Shooting-Start	Shooting-End/ Reversal-Start				
Case Designation			H38	H37	H36	H34	H32
t, s	0	3.00	10.13	12.14	14.27	20.15	24.12
s, ft	0	128	412	488	566	770	900
V, ft/s	42.9	42.0	38.0	37.0	36.0	33.5	32.0
N, rpm	133.3	93.0	79.4	77.3	75.2	70.0	66.8

Quarter Power Cases

Phase	Initial Conditions/ Windmill-Start	Windmill-End/ Shooting-Start	Shooting-End/ Reversal-Start				
Case Designation			Q33	Q31	Q30	Q28	Q27
t, s	0	3.00	4.29	9.83	14.48	19.63	23.38
s, ft	0	102	144	322	462	610	713
V, ft/s	34.0	33.5	33.0	31.0	29.5	28.0	27.0
N, rpm	105.8	75.0	69.3	64.7	61.6	58.5	56.4

3.4 Results for a Typical Case

The simulation printout for a typical full power crash back case, F40-4, is shown in Figure 3-2. At the start (t=0 s) the ship is operating at the full power point. The time and reach are both given initial values of zero. At the full power point, the ship speed is 54.01 ft/s and the propeller speed is 168 rpm. Due to round of errors, the propeller thrust does not quite equal the drag and therefore the acceleration is slightly different from zero. The motor and propeller torques are both equal to 1.171 X 10^6 lb-ft. Since the motor is considered lossless, its input power and output power are both 37444 hp. Under steady-state conditions, this is also the power delivered to the propeller. Under dynamic conditions, this is the electrical power input to the motor. The energy is mega-joules is only calculated and integrated during reversal, otherwise it is set equal to zero. The last column lists the propeller first angle-of-advance coefficient.

At t=3 s the propeller speed has been ramped down to 115 rpm which is approximately the windmill speed. After this time the motor torque is set equal to zero and the ship is allowed to shoot.

When the ship speed has decreased to 40 ft/s the motor torque is increased from zero to -120 percent (-1.405 X 10^6 lb-ft) and then held constant throughout the reversal phase. The double line entry at this time, 19.977 s, is due to the step change in the motor torque and power. During the reversal phase, the printing interval is changed to 0.0[illegible] seconds, otherwise a one second interval is used.

SEGMAG II   FULL POWER CRASH BACK

TIME, S	REACH, FT	VEL, FT/S	ACC, FT/S**2	DRAG, LB	THRUST, LB	N-PROP, RPM	Q-MOTOR, M LB-FT	Q-PROP, M LB-FT	P-MOTOR, HP	ENERGY, MJ	THETA, DEG
0,000	0,0	54,01	0,001	266913.	267104.	168,00	1,171	1,171	37444.	0,000	49,975
1,000	54,0	53,84	-0,342	265202.	172397.	150,33	0,651	0,751	18621.	0,000	52,986
2,000	107,6	53,34	-0,636	260354.	87711.	132,67	0,305	0,405	7696.	0,000	56,118
3,000	160,5	52,57	-0,891	252884.	11037.	115,00	0,001	0,101	12.	0,000	59,433
4,000	212,7	51,64	-0,937	243994.	-10236.	108,06	0,000	0,015	0.	0,000	60,533
5,000	263,8	50,72	-0,907	235353.	-10747.	105,93	0,000	0,011	0.	0,000	60,581
6,000	314,1	49,83	-0,876	227153.	-10411.	104,06	0,000	0,010	0.	0,000	60,583
7,000	363,5	48,96	-0,846	219375.	-10056.	102,26	0,000	0,010	0.	0,000	60,583
8,000	412,0	48,13	-0,817	211989.	-9717.	100,52	0,000	0,010	0.	0,000	60,583
9,000	459,8	47,33	-0,790	204970.	-9396.	98,84	0,000	0,009	0.	0,000	60,583
10,000	506,7	46,55	-0,764	198294.	-9090.	97,22	0,000	0,009	0.	0,000	60,583
11,000	552,9	45,80	-0,740	191939.	-8798.	95,65	0,000	0,009	0.	0,000	60,583
12,000	598,3	45,07	-0,717	185885.	-8521.	94,13	0,000	0,009	0.	0,000	60,583
13,000	643,0	44,37	-0,694	180113.	-8256.	92,66	0,000	0,008	0.	0,000	60,583
14,000	687,1	43,68	-0,673	174605.	-8004.	91,23	0,000	0,008	0.	0,000	60,583
15,000	730,4	43,02	-0,653	169346.	-7763.	89,84	0,000	0,008	0.	0,000	60,583
16,000	773,1	42,38	-0,633	164321.	-7532.	88,50	0,000	0,008	0.	0,000	60,583
17,000	815,2	41,75	-0,615	159517.	-7312.	87,20	0,000	0,007	0.	0,000	60,583
18,000	856,5	41,15	-0,597	154920.	-7101.	85,93	0,000	0,007	0.	0,000	60,583
19,000	897,5	40,56	-0,580	150520.	-6900.	84,70	0,000	0,007	0.	0,000	60,583
19,977	936,8	40,00	-0,564	146400.	-6711.	83,54	0,000	0,007	0.	0,000	60,583
19,977	936,8	40,00	-0,564	146400.	-6711.	83,54	-1,405	0,007	-22347.	0,000	60,583
20,000	937,7	39,99	-0,636	146297.	-26195.	77,89	-1,405	-0,065	-20837.	-0,376	62,258
20,050	939,7	39,95	-0,770	146041.	-62836.	66,74	-1,405	-0,206	-17854.	-1,096	65,723
20,100	941,7	39,91	-0,906	145735.	-99971.	56,79	-1,405	-0,334	-15191.	-1,711	68,984
20,150	943,7	39,86	-1,036	145380.	-135729.	48,01	-1,405	-0,475	-12843.	-2,233	71,986
20,200	945,7	39,81	-1,148	144982.	-166582.	40,38	-1,405	-0,597	-10803.	-2,673	74,681
20,250	947,7	39,75	-1,259	144543.	-197029.	33,83	-1,405	-0,721	-9051.	-3,042	77,056
20,300	949,7	39,68	-1,353	144068.	-223064.	28,30	-1,405	-0,827	-7571.	-3,351	79,100
20,350	951,7	39,61	-1,435	143562.	-245876.	23,63	-1,405	-0,922	-6322.	-3,609	80,849
20,400	953,7	39,54	-1,506	143029.	-265476.	19,77	-1,405	-1,006	-5288.	-3,825	82,311
20,450	955,6	39,46	-1,563	142475.	-281520.	16,57	-1,405	-1,075	-4433.	-4,006	83,531
20,500	957,6	39,38	-1,609	141902.	-294637.	13,92	-1,405	-1,131	-3724.	-4,158	84,548
20,550	959,6	39,30	-1,648	141316.	-305872.	11,70	-1,405	-1,163	-3129.	-4,285	85,405
20,600	961,5	39,22	-1,686	140717.	-316579.	9,64	-1,405	-1,179	-2580.	-4,391	86,201
20,650	963,5	39,13	-1,720	140107.	-326501.	7,72	-1,405	-1,194	-2066.	-4,478	86,949
20,700	965,4	39,04	-1,751	139486.	-335093.	5,93	-1,405	-1,208	-1586.	-4,546	87,652
20,750	967,4	38,96	-1,762	138857.	-339083.	4,24	-1,405	-1,212	-1134.	-4,597	88,318
20,800	969,3	38,87	-1,751	138231.	-336830.	2,51	-1,405	-1,206	-672.	-4,630	89,000
20,850	971,3	38,78	-1,717	137615.	-328103.	0,61	-1,405	-1,170	-163.	-4,646	89,757
20,864	971,8	38,70	-1,706	137441.	-325393.	0,00	-1,405	-1,158	-0.	-4,647	90,000

FIGURE 3-2a Simulation Printout (Typical)

TIME, S	REACH, FT	VEL, FT/S	ACC, FT/S**2	DRAG, LB	THRUST, LB	N-PROP, RPM	Q-MOTOR, M LB-FT	Q-PROP, M LB-FT	P-MOTOR, HP	ENERGY, MJ	THETA, DEG
20,963	975,7	38,62	-1,312	136445.	-219577.	-8,00	-1,405	-0,836	2140.	0,000	93,201
20,963	975,7	38,62	-1,312	136445.	-219577.	-8,00	-1,639	-0,836	2496.	0,000	93,201
22,000	1014,8	36,81	-1,900	123995.	-391361.	-65,89	-1,639	-1,547	20563.	0,000	115,794
23,000	1050,6	34,88	-1,920	111320.	-409541.	-70,53	-1,639	-1,627	22012.	0,000	118,634
24,000	1084,6	32,98	-1,877	99545.	-409734.	-72,99	-1,639	-1,615	22777.	0,000	120,857
25,000	1116,6	31,11	-1,865	88540.	-417512.	-76,34	-1,639	-1,597	24447.	0,000	124,214
26,000	1146,8	29,27	-1,800	7[illegible]88.	-409932.	-88,22	-1,639	-1,566	27532.	0,000	129,13[illegible]
27,000	1175,2	27,54	-1,660	69383.	-380859.	-104,71	-1,639	-1,534	32676.	0,000	135,75[illegible]
28,000	1201,9	25,95	-1,530	61593.	-353367.	-121,03	-1,625	-1,558	37444.	0,000	141,553
29,000	1227,1	24,46	-1,457	54758.	-340460.	-127,41	-1,543	-1,517	37444.	0,000	144,582
30,000	1250,9	23,02	-1,432	48472.	-339943.	-128,61	-1,529	-1,531	37444.	0,000	146,462
31,000	1273,2	21,60	-1,400	42693.	-337254.	-127,76	-1,539	-1,547	37444.	0,000	147,945
32,000	1294,1	20,22	-1,371	37393.	-334449.	-126,50	-1,555	-1,562	37444.	0,000	149,379
33,000	1313,6	18,86	-1,346	32539.	-332595.	-125,02	-1,573	-1,583	37444.	0,000	150,811
34,000	1331,8	17,52	-1,323	28098.	-330778.	-123,32	-1,595	-1,604	37444.	0,000	152,242
35,000	1348,7	16,21	-1,302	24047.	-329295.	-121,68	-1,616	-1,625	37444.	0,000	153,736
36,000	1364,2	14,92	-1,285	20363.	-328296.	-120,15	-1,637	-1,643	37444.	0,000	155,305
37,000	1378,5	13,64	-1,274	17018.	-328039.	-118,97	-1,639	-1,646	37129.	0,000	156,996
38,000	1391,5	12,37	-1,262	14001.	-328294.	-117,66	-1,639	-1,647	36718.	0,000	158,725
39,000	1403,2	11,11	-1,250	11303.	-327863.	-116,36	-1,639	-1,645	36314.	0,000	160,519
40,000	1413,7	9,87	-1,243	8910.	-328198.	-115,31	-1,639	-1,645	35986.	0,000	162,414
41,000	1423,0	8,63	-1,236	6813.	-328015.	-114,20	-1,639	-1,646	35640.	0,000	164,367
42,000	1431,0	7,40	-1,229	5006.	-328351.	-113,36	-1,639	-1,642	35376.	0,000	166,414
43,000	1437,8	6,17	-1,225	3483.	-328879.	-112,74	-1,639	-1,643	35182.	0,000	168,542
44,000	1443,5	4,95	-1,223	2239.	-328860.	-112,12	-1,639	-1,640	34989.	0,000	170,720
45,000	1447,7	3,73	-1,220	1271.	-329732.	-111,96	-1,639	-1,640	34941.	0,000	172,973
46,000	1450,8	2,51	-1,220	575.	-330512.	-111,69	-1,639	-1,634	34855.	0,000	175,250
47,000	1452,7	1,28	-1,223	151.	-331614.	-111,92	-1,639	-1,636	34927.	0,000	177,566
48,000	1453,4	0,06	-1,229	0.	-333341.	-112,50	-1,639	-1,636	35109.	0,000	179,889
48,048	1453,4	0,00	-1,229	0.	-333432.	-112,53	-1,639	-1,636	35116.	0,000	180,000

FIGURE 3-2b Simulation Printout (Typical)

At t=20.864 s, the propeller is stalled. The total energy produced during the 0.887 second reversal period is 4.647 MJ (per shaft). The propeller torque hits a maximum at about 5 rpm. The ship deceleration rate from the start to the finish of the reversal process has increased threefold as a result of the large negative thrust developed by the propeller as it is slowed below the windmill speed.

After stall the propeller torque and thrust drop sharply. At a propeller speed of -8 rpm, the motor torque is changed from -120 percent to -140 percent ($-1.[illegible]39 \times 10^6$ lb-ft). Again there is a double entry at this point, t=20.963 s, to signify the step change in the torque and motor power. The power is again positive since the motor is absorbing power. The energy is no larger calculated and it is set to zero on the printout.

The propeller speed continues to increase in the negative rotational direction. At t=28 s; the propulsion system becomes power limited. The absolute value of the propeller speed increases slightly for two more seconds and then starts to decrease. At t=37 s the propulsion system is no longer power limited and the motor torque is again -140 percent.

At t=48.048 s, the ship is dead in the water. The head reach is 1453.4 ft.

4. CONSTANT TORQUE CASES

For these cases, the motor torque is held at a constant value throughout the reversal phase, and afterwards, until the propeller has achieved a speed of -8 rpm. At this point, the motor torque may assume a different value which is held constant until the ship is dead in the water.

4.1 Full Power

For the 18 cases presented in this section, the ship is in the full power configuration. At the start of the crash back maneuver (t=0 s) the ship is being driven ahead at full power steady-state operating conditions:

$V = 54.01$ ft/s

$F = 266{,}913$ lb

$N = 168$ rpm

$Qp = 100\% = 1.171 \times 10^6$ lb-ft

$Qm = 100\% = 1.171 \times 10^6$ lb-ft

$Pm = 37444$ hp

At t=3 s, the propeller speed has been ramped down linearly with time to 115 rpm which is the approximate windmill speed. The ship speed has decreased to 52.57 ft/s and the reach is 160.5 ft. After this time, the ship is allowed to shoot (i.e., zero motor torque) until the initiation of the propeller reversal process.

The end of this section contains a listing of the main features for all 18 cases, however, not all of the cases are discussed in detail.

Baseline

The baseline case serves as a convenient reference point for comparison with other cases. "Baseline" in no way signifies the best or most desireable case. The baseline case, denoted by F40-6, starts the reversal phase at a ship speed of 40 ft/s (t=19.977 s). The motor torque is held at a constant value of -120 percent until the ship is dead in the water at t=51.5 s with a head reach of 1507 ft.

Figure 4-1 shows the ship speed, propeller speed, motor torque, propeller torque, and motor power plotted against time. Figure 4-2 shows the motor power, propeller speed, energy, propeller torque, and motor torque for the 0.887 second reversal phase only. For convenience, the negative motor power and negative energy are plotted in order to show positive values on the graph. The energy totals 4.647 MJ when the propeller achieves zero rotational speed. This is the energy that the propulsion system would have to absorb on a half ship basis.

Effect of changing the reversal torque

Two cases were run for comparison with the baseline case, i.e., where the only change is the motor torque during reversal which is held constant until the propeller speed is -8 rpm and then is changed back to the baseline value of -120 percent. Cases F40-1 and F40-9 were run with reversal torques of -150 and -100 percent respectively.

For these cases, the maximum changes in the time to stop the ship and the head reach are neglegible, being 0.4 seconds and 13 ft respectively.

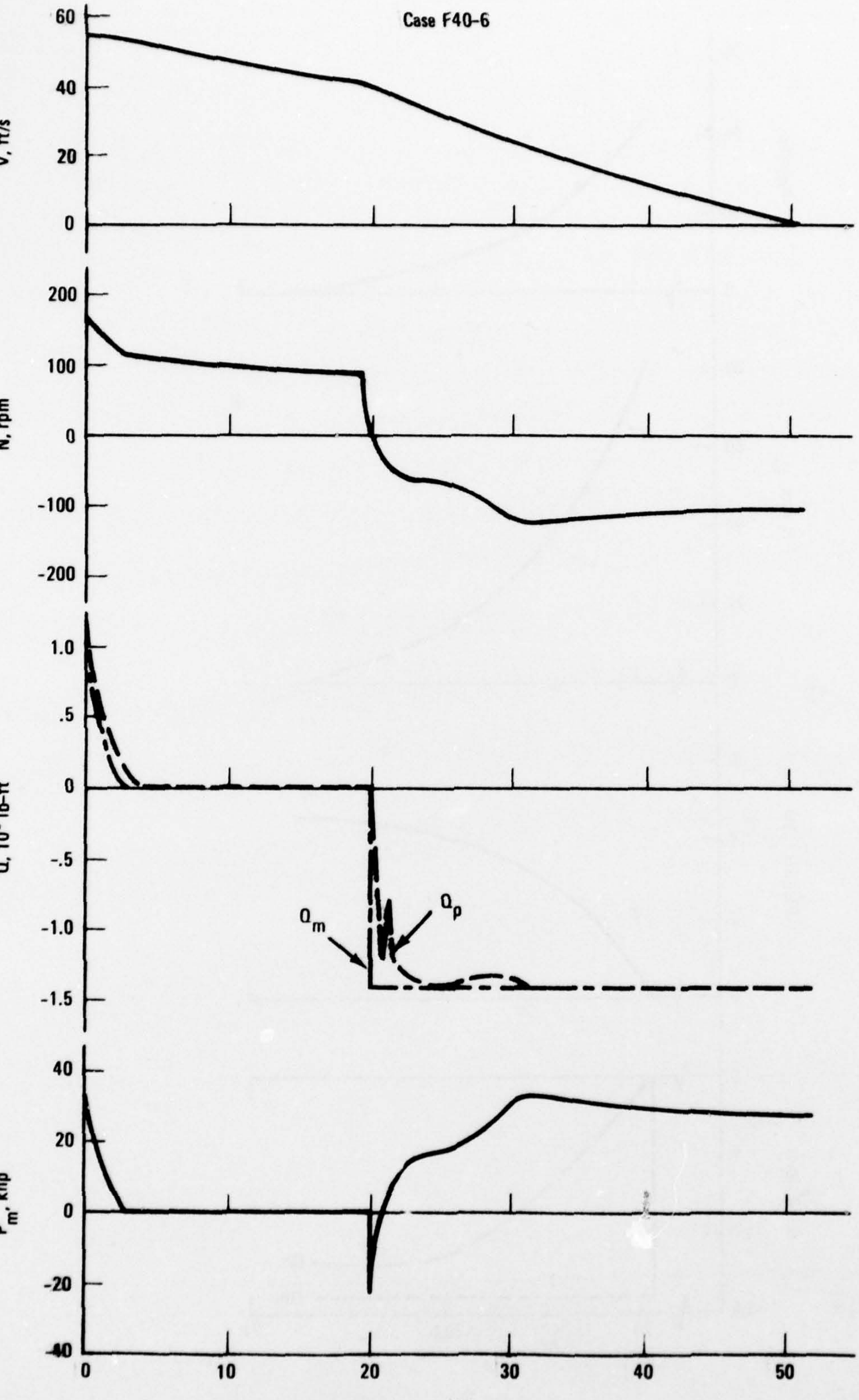


Figure 4-1 Baseline Profile, Full Power

15

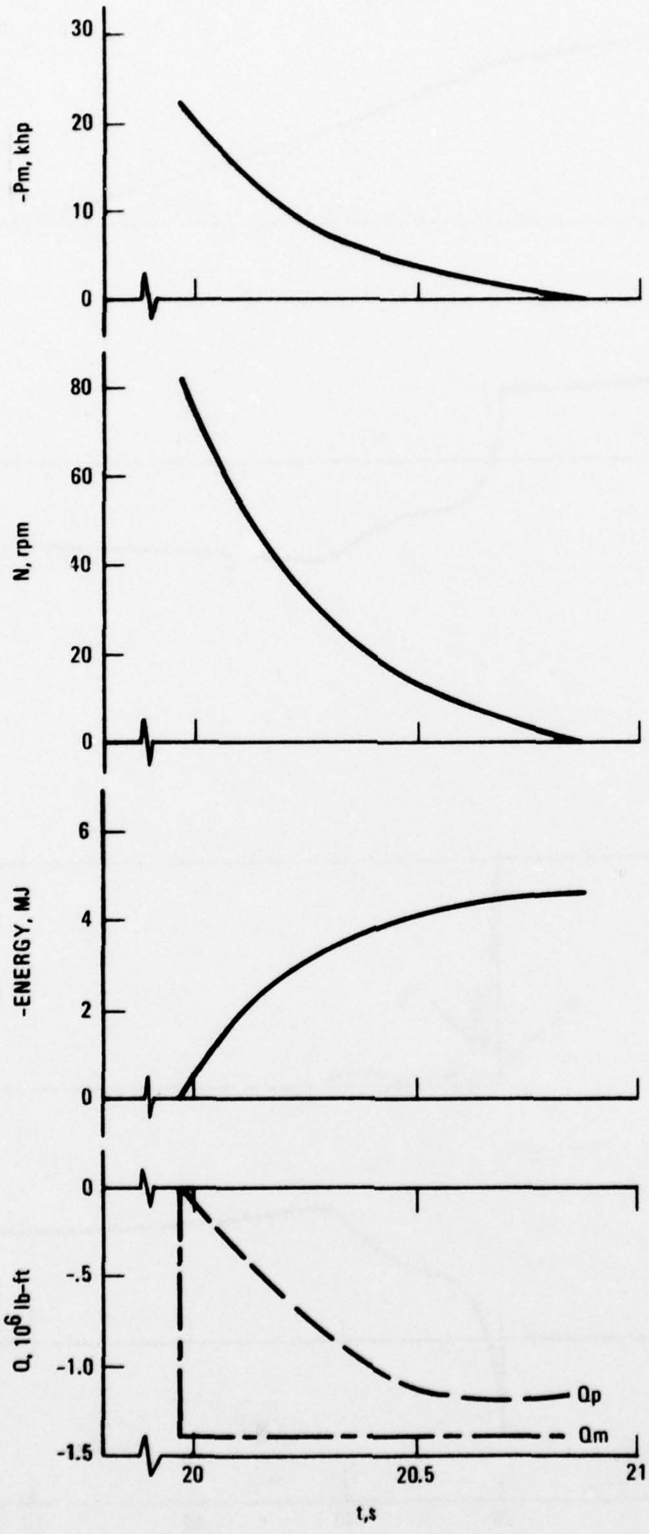


Figure 4-2 Baseline Reversal Characteristics, Full Power

On the other hand, the reversal characteristics as shown in Figure 4-3 differ considerably as the reversal torque is altered.

As the motor torque is increased (negatively) the duration of the reversal phase and the energy generated both decrease. In the limit (i.e. $Q_m \to -\infty$), the duration would go to zero and the energy generated would be equal to the rotational kinetic energy of the propeller-shaft-motor rotor at the start of the reversal phase which is 2.8 MJ.

As the absolute value of the motor torque is decreased below the baseline torque (-120%), the duration and energy start increasing rapidly due to the greater difficulty in overcoming the peak propeller torque. At a ship speed of 40 ft/s, the peak propeller torque near stall is -109 percent of rated motor torque. In order for a motor torque of -100 percent to stall the propeller, the ship speed must be down to at least 38.3 ft/s and, in fact, for case F40-9, the ship speed had decreased to 36.8 ft/s by the end of the reversal phase.

Effect of changing the torque after reversal

Five cases, F40-3, F40-4, F40-5, F40-7, and F40-8, were run for comparison with the baseline. Figure 4-4a shows the motor torque vs. time for each case from t=20.864 s (N=0 rpm) until the ship is dead in the water. The motor torque for the -140 and -150 percent torque cases must be reduced part of the time due to the power limitation of 37,444 hp.

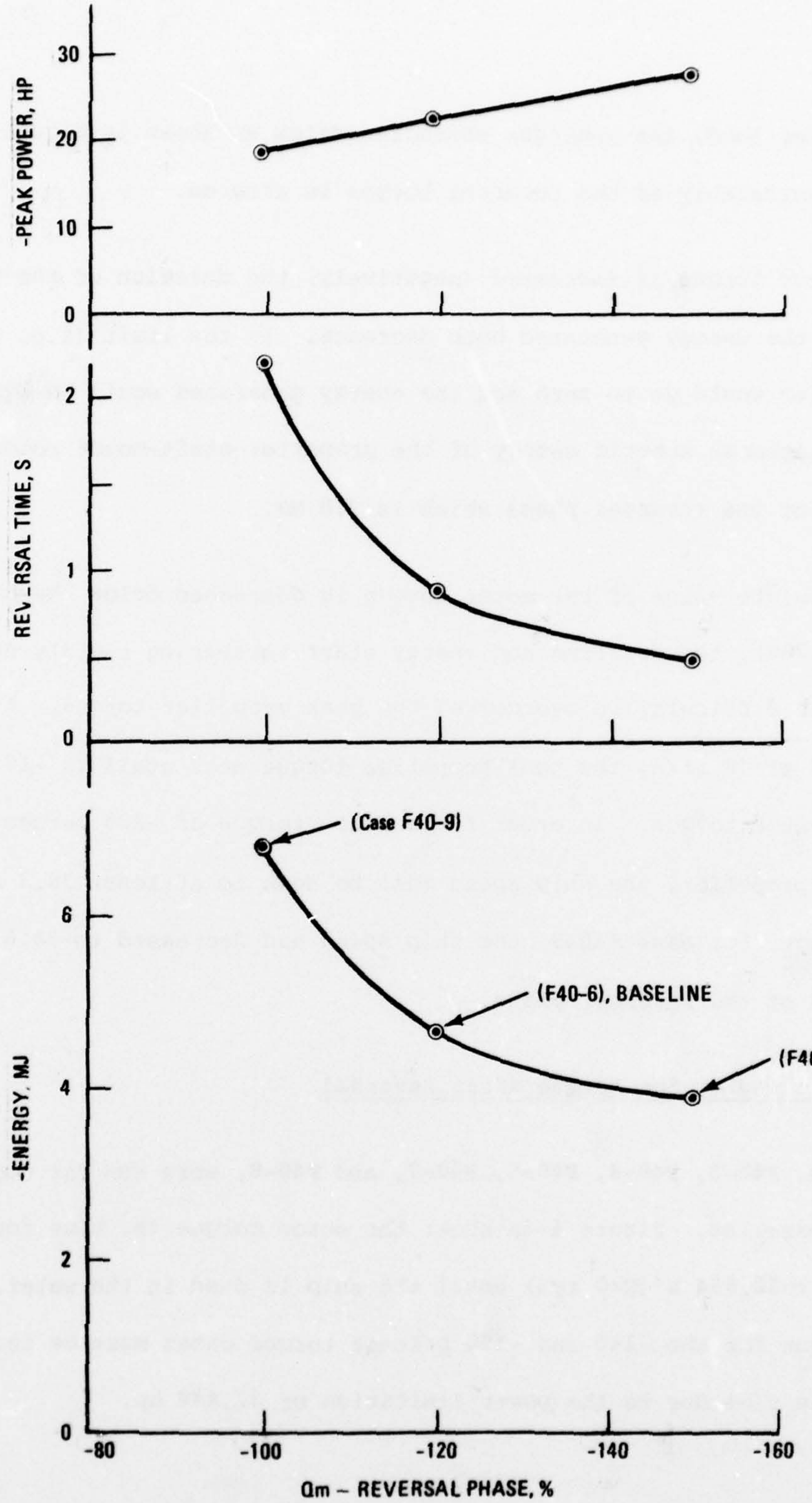


Figure 4-3 Reversal Qm Change, Full Power

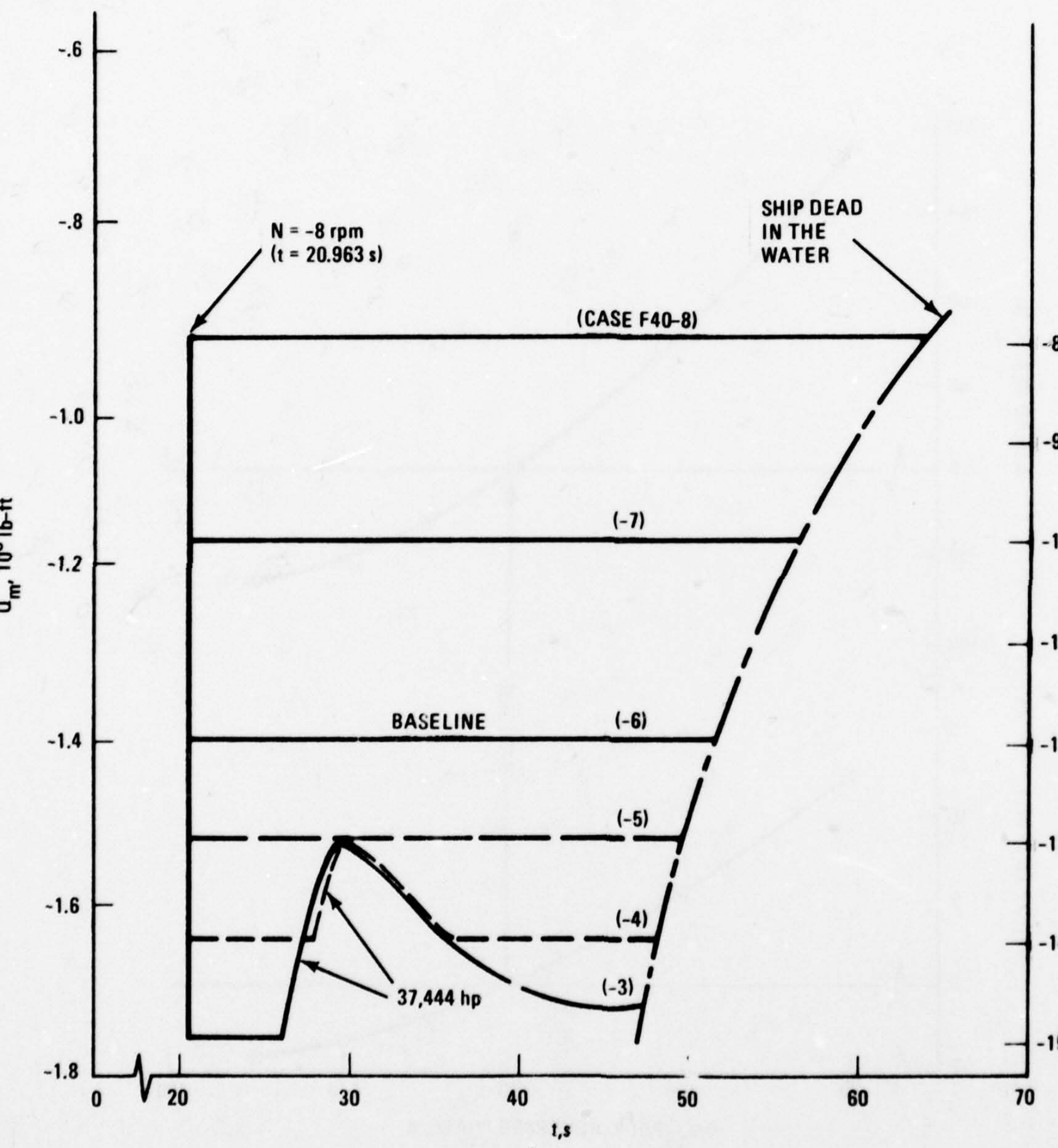


Figure 4-4a Propeller Reversed Qm Change, Full Power

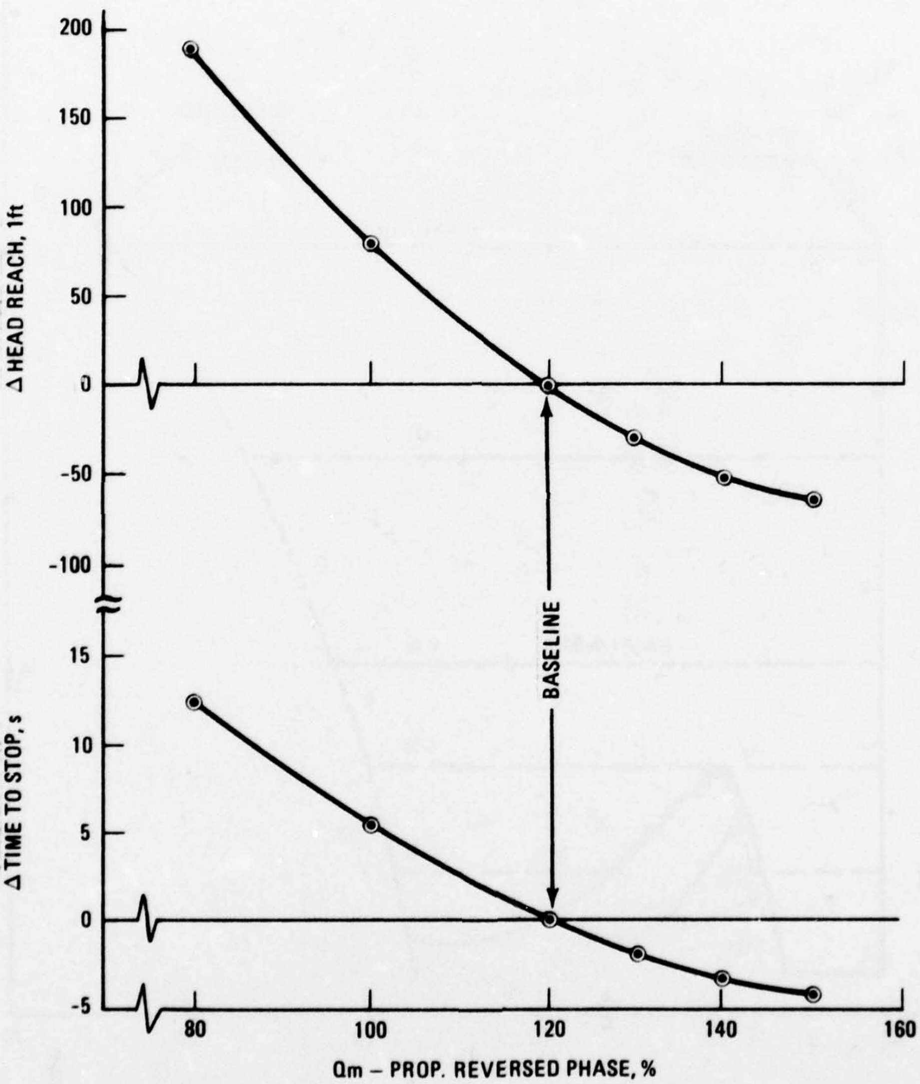


Figure 4-4b Propeller Reversed Qm Change, Full Power

Figure 4-4b shows the change in the time to stop the ship and the head reach with respect to the baseline case. As can be seen from this plot, the value of the motor torque in the reversed propeller phase has a significant effect on the crash back performance.

Effect of changing the start of reversal

Three cases, F35-1, F42-1, and F45-3 were run for comparison with the baseline. Figure 4-5 shows the reversal characteristics, time to stop the ship and head reach vs. the ship speed at which reversal is initiated. There is a considerable change in all of these parameters as a function of the start of reversal.

Case Summary

A summary listing for the 18 full power crash back cases is shown in Table 4-1. Most of the information listed is related to the reversal phase. Note that the energy produced during reversal and the peak motor power are on a per motor shaft basi . Here, the negative signs for both of these quantities have been dropped for convenience. The motor torque in the propeller reversed phase is given in two parts, both of which are constant with the exception of the motor power limitation which only applies to two cases. The time to stop the ship and the head reach are listed in the last two columns.

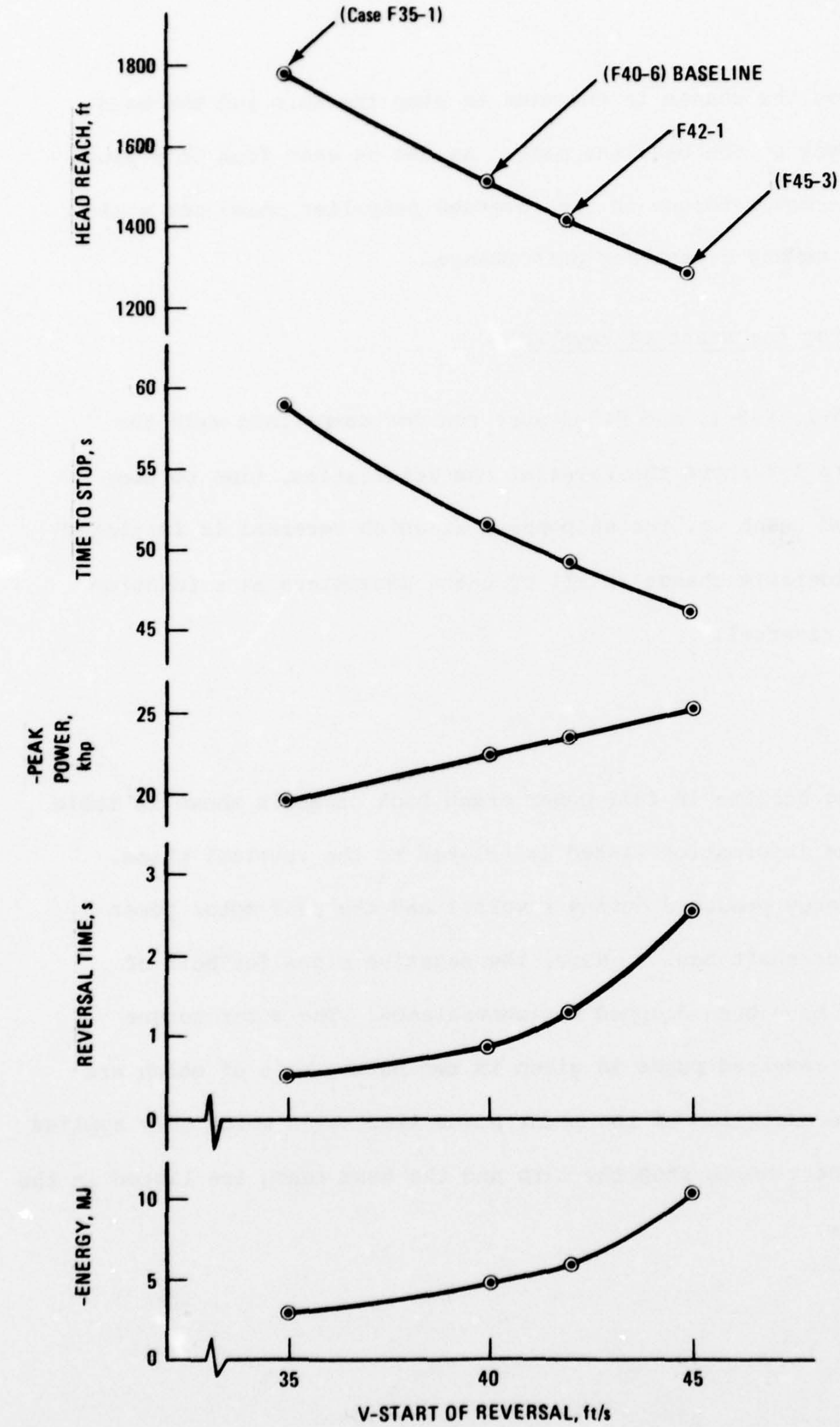


Figure 4-5 Start of Reversal Change, Full Power

Table 4-1 Constant Torque Full Power Crash Back Summary

all cases:

windmill down:	t, s	S, ft	V, ft/s	N, rpm	Qm, %	Pm, hp
start	0	0	54.01	168	100	37,444
end	3	161	52.57	115	∽ 0	∽ 0

case	reversal							propeller reversed		total	head
	start		Qm,		total		peak	N=0→	N=-8→	time	reach,
	V,	t,			energy,	time,	power,	-8 rpm	V=0	to stop,	
	ft/s	s	%		MJ	s	hp	Qm, %	Qm, %	s	ft
F45-1	45	12.100	-150	constant	5.971	0.826	31,422	-150	-120	46.0	1276
-2									-100	51.4	1366
-3			-120		10.211	2.556	25,142	-120	-120	46.2	1282
-4									-100	51.3	1364
-5			-100		17.343	5.027	20,954	-100	-120	46.8	1305
-6									-100	51.7	1379
F42-1	42	16.600	-120		5.969	1.296	23,465	-120	-120	49.2	1412
F40-1	40	19.977	-150		3.906	0.488	27,930	-150	-120	51.4	1504
-2									-100	56.5	1583
-3			-120		4.647	0.887	22,347	-120	-150*	47.4	1442
-4									-140*	48.0	1453
-5									-130	49.5	1476
-6									-120	51.5	1507
-7									-100	56.5	1585
-8									- 80	63.7	1694
-9			-100		6.769	2.180	18,625	-100	-120	51.8	1517
-10									-100	56.7	1590
F35-1	35	30.100	-120		2.926	0.511	19,544	-120	-120	58.9	1780

* power limited (37,444 hp)

Table 4-2 lists some typical motor torques in both percent of rated motor torque and in lb-ft. Also shown are the component currents in percent of rated current for the motor and generator.

Table 4-2. Component Currents, Full Power Configuration

Qm		component current, % of rated current	
%	lb-ft	motor	generator
150	1.757×10^6	150	118.4
140	1.639 X 106	140	110.5
130	1.522×10^6	130	102.6
120	1.405 X 106	120	94.7
110	1.288×10^6	110	86.8
100	1.171 X 106	100	78.9

4.2 Half Power

For the 13 cases presented in this chapter, the ship is in the half power configuration. At the start of the crash back maneuver (t=0 s) the ship is being driven ahead at half power steady-state operating conditions:

$V = 42.87$ ft/s

$F = 68,162$ lb

$N = 133.3$ rpm

$Qp = 0.738 \times 10^6$ lb-ft

$Qm = 0.738 \times 10^6$ lb-ft

$Pm = 18722$ hp

At t=3 s, the propeller speed has been ramped down to 93 rpm. The ship speed has decreased to 41.98 ft/s and the reach is 127.7 ft. After this time, the ship is allowed to shoot until the reversal phase is initiated.

The end of this section contains a listing of the main features for all 13 cases.

Baseline

The baseline case, denoted by H34-5, starts the reversal phase at a ship speed of 33.5 ft/s (t=20.15 s). The motor torque is held at a constant value of -76 percent until the ship is dead in the water at t=61.1 s with a head reach of 1285 ft. The generator current is 120 percent of its 9500 A rated current value.

During the 1.662 second reversal phase, a total energy of 3.831 MJ is produced by the motor.

Effect of changing the reversal torque

Cases H34-2 and H34-7 with reversal torques of -95 percent and -63.3 percent were run for comparison with the baseline. The time to stop the ship and the head reach is approximately the same for these three cases. The reversal characteristics as a function of the motor torque are shown in Figure 4-6.

Effect of changing the torque after reversal

Two cases, H34-4 and H34-6, were run for comparison with the baseline. Figure 4-7a shows the motor torque for each in the propeller reversed phase,

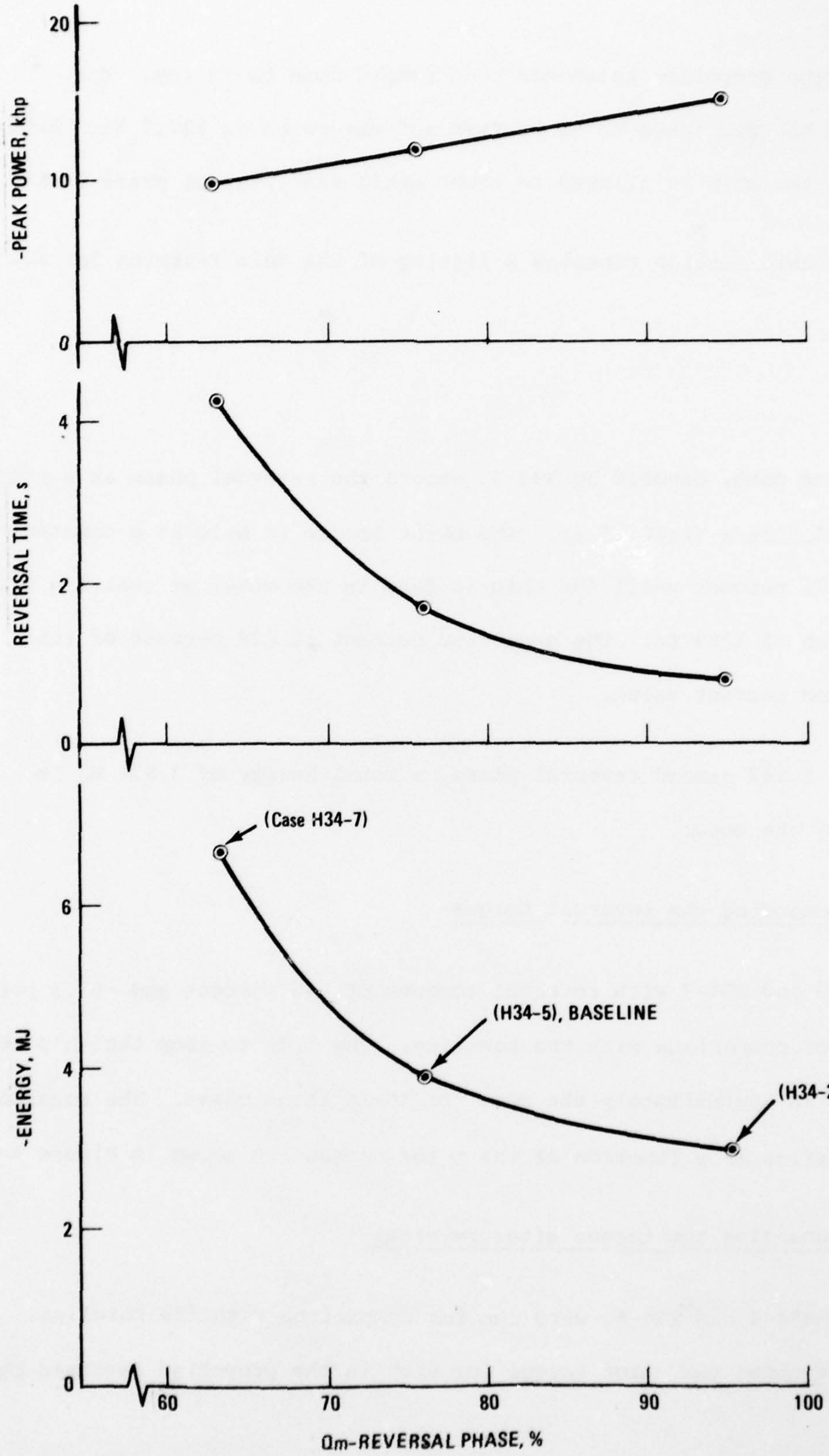


Figure 4-6 Reversal Qm Change, Half Power

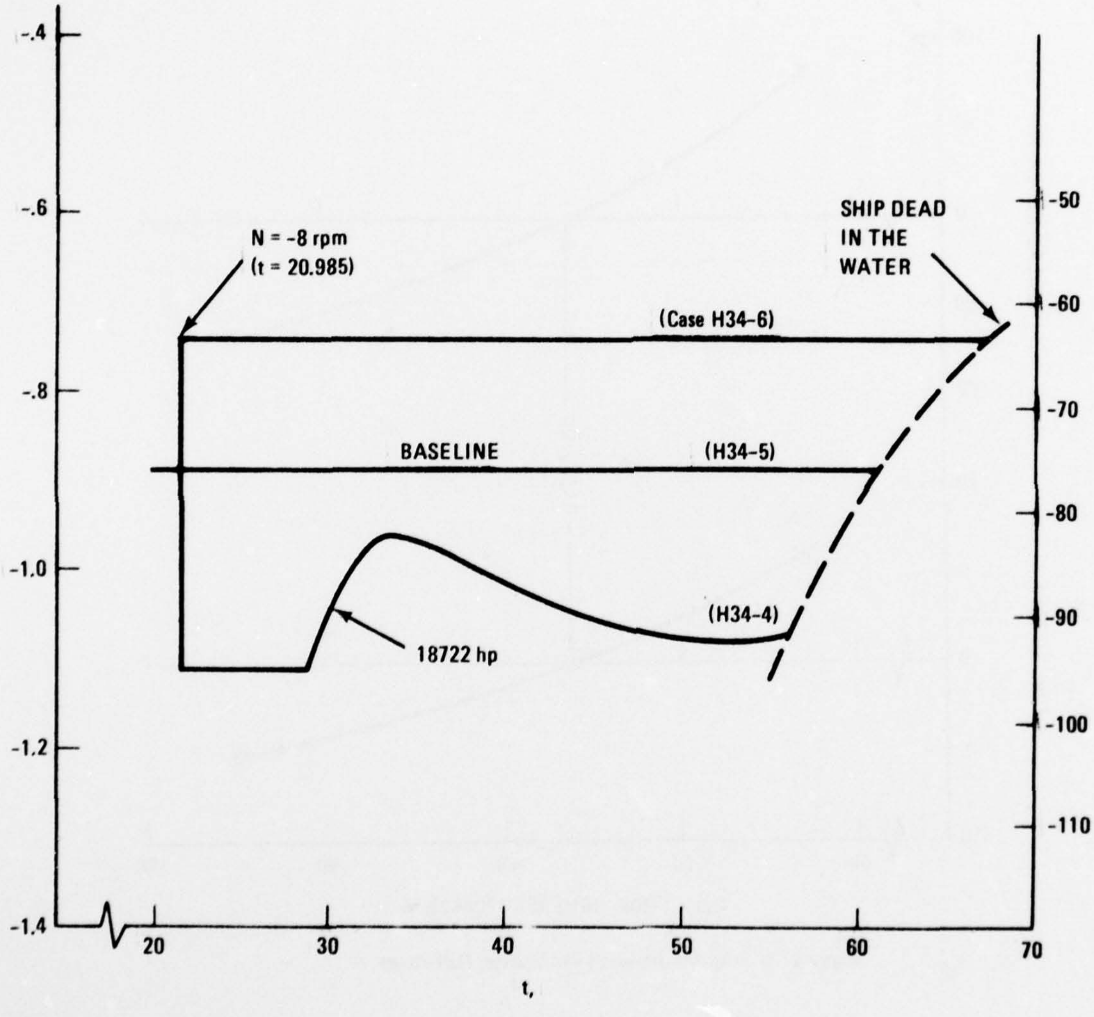


Figure 4-7a Propeller Reversed Qm Change, Half Power

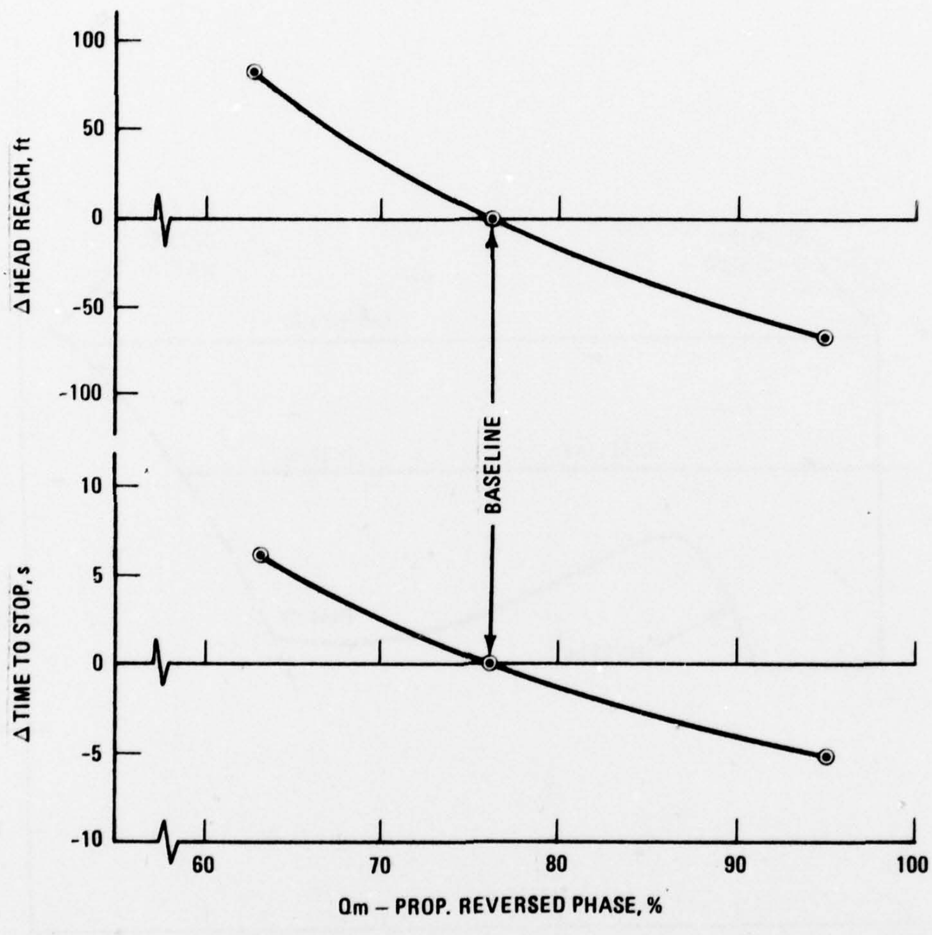


Figure 4-7b Propeller Reversed Qm Change, Half Power

i.e., from t=21.812 s until the ship is dead in the water. The motor torque for the -95 percent torque case must be reduced part of the time due to the power limitation of 18722 hp.

Figure 4-7b shows the change in the time to stop the ship and the head reach with respect to the baseline case.

Effect of changing the start of reversal

Three cases, H38-3, H36-1, and H32-1, were run for comparison with the baseline. Figure 4-8 shows the reversal characteristics, time to stop the ship and head reach vs. the ship speed at which reversal is initiated.

Case Summary

A summary listing for the 13 half power crash back cases is shown in Table 4-3. Table 4-4 lists some typical motor torques and gives the corresponding component currents.

Table 4-4. Component Currents, Half Power Configuration

Qm		component current, % of rated current	
%	lb-ft	motor	generator
95	1.112×10^6	95	150
76	0.890×10^6	76	120
63.3	0.742×10^6	63.3	100

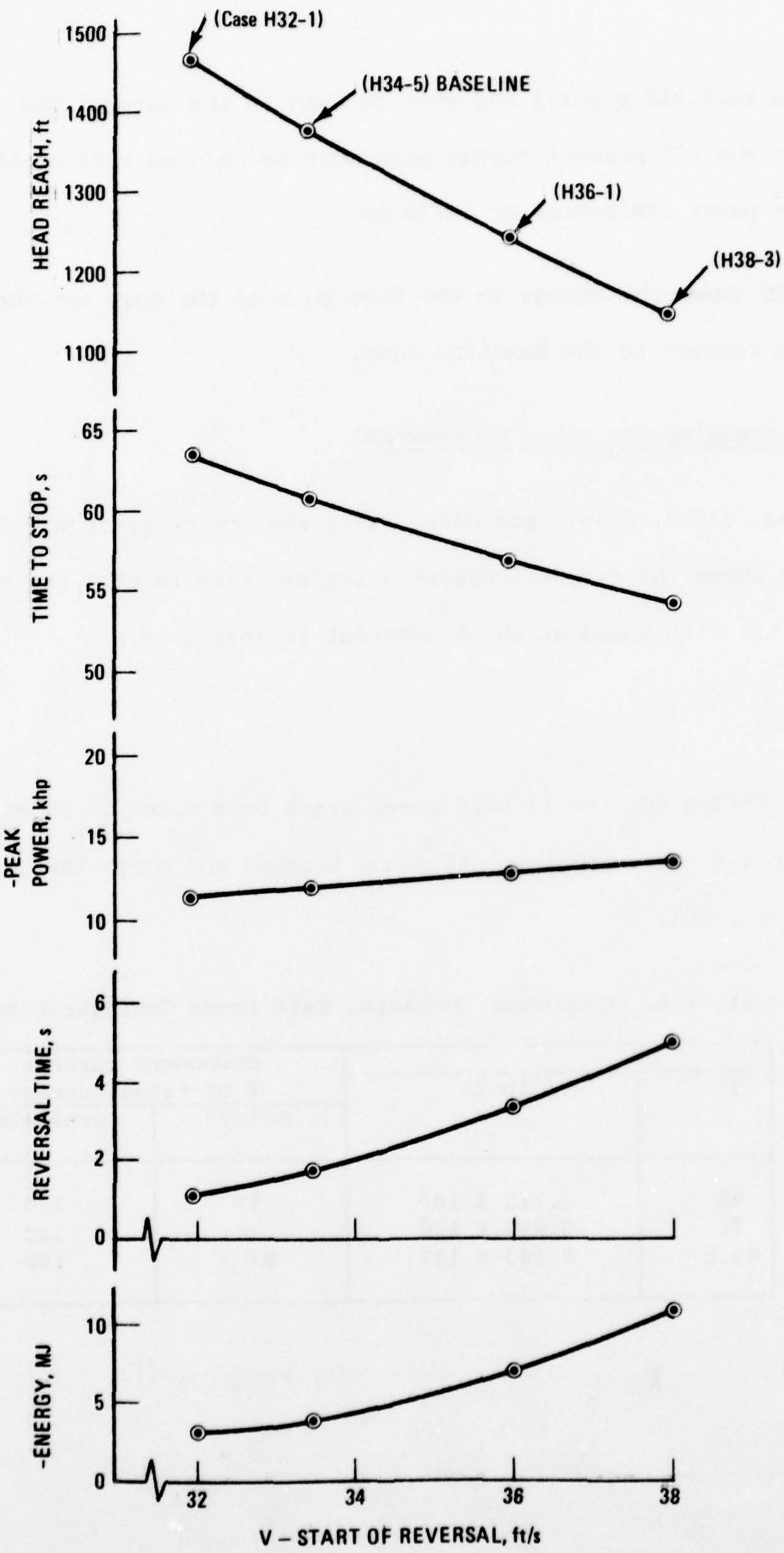


Figure 4-8 Start of Reversal Change, Half Power

Table 4-3 Constant Torque Half Power Crash Back Summary

all cases:

windmill down:	t, s	S, ft	V, ft/s	N, rpm	Qm, %	Pm, hp
start	0	0	42.87	133.3	63	18,722
end	3	128	41.98	93	→ 0	→ 0

case	reversal						propeller reversed		total time to stop,	head reach,
	start		Qm,	total		peak power,	N=0→ -8 rpm	N=-8→ V=0		
	V, ft/s	t, s	%	energy, MJ	time, s	hp	Qm, %	Qm, %	s	ft
H38-1	38	10.126	-95 constant	5.280	1.721	16,803	-95	-95*	48.7	1061
-2								-76	54.3	1142
-3			-76	10.470	4.866	13,448	-76	-76	54.6	1153
H36-1	36	14.271	-76	6.760	3.352	12,740	-76	-76	57.2	1250
H34-1	33.5	20.150	-95	2.918	0.736	14,812	-95	-95*	55.7	1310
-2								-76	61.0	1381
-3								-63.3	67.5	1465
-4			-76	3.831	1.662	11,855	-76	-95*	56.0	1318
-5								-76	61.1	1385
-6								-63.3	67.5	1466
-7			-63.3	6.613	4.249	9,884	-63.3	-76	61.6	1400
-8								-63.3	67.8	1473
H32-1	32	24.115	-76	3.011	1.152	11,325	-76	-76	63.9	1474

* power limited (18722 hp)

4.3 Quarter Power

For the 12 cases presented in this chapter, the ship is in the quarter power configuration. At the start of the crash back maneuver (t=0 s) the ship is being driven ahead at quarter power steady-state operating conditions:

$$V = 34.02 \text{ ft/s}$$

$$F = 105{,}898 \text{ lb}$$

$$N = 105.8 \text{ rpm}$$

$$Q_p = 0.465 \times 10^6 \text{ lb-ft}$$

$$Q_m = 0.465 \times 10^6 \text{ lb-ft}$$

$$P_m = 9361 \text{ hp}$$

At t=3 s, the propeller speed has been ramped down to 75 rpm. The ship speed has decreased to 33.48 ft/s and the reach is 101.5 ft. After this time, the ship is allowed to shoot until the reversal phase is initiated.

The end of this section contains a listing of the main features for all 12 cases.

Baseline

The baseline case, denoted by Q28-4, starts the reversal phase at a ship speed of 28 ft/s (t=19.6 s). The motor torque is held at a constant value of -76 percent throughout the reversal phase. An energy of 1.881 MJ is produced during the 0.651 second reversal.

When the propeller speed achieves a value of -8 rpm at t=20.4 s, the motor torque is changed from -76 percent to -63.3 percent. However, during most of the propeller reversed phase (t=31 s to t=65.4 s), the torque must be reduced due to the power limitation of 9361 hp. At t=65.4 s, the ship is dead in the water and the head reach is 1180 ft.

At a motor torque of -76 percent, the generator operates at 120 percent of its rated current.

Effect of changing the reversal torque

Cases Q28-1 and Q28-6 with reversal torques of -95 percent and -63.3 percent were run for comparison with the baseline. The head reach and time to stop the ship is almost the same for all three cases. The reversal characteristics as a function of motor torque are shown in Figure 4-9.

Effect of changing the torque after reversal

Three cases were run for comparison with the baseline. Figure 4-10a shows the motor torque for each in the propeller reversed phase, i.e., from t=20.282 s until the ship is dead in the water. Except for the -50 percent torque case, all motor torques must be reduced a large part of the time due to the power limitation of 9361 hp.

Figure 4-10b shows the change in the time to stop the ship and the head reach with respect to the baseline case.

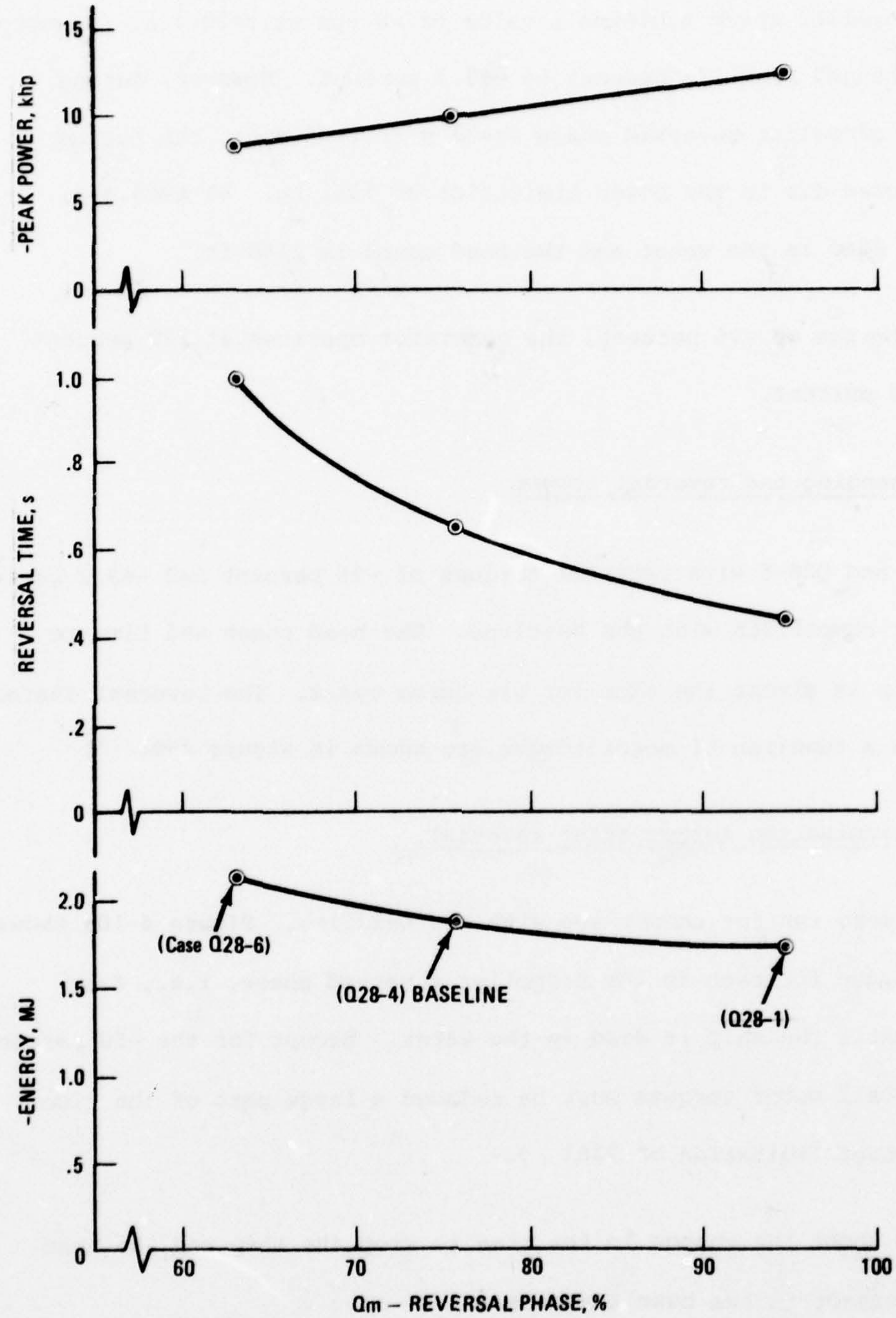


Figure 4-9 Reversal Qm Change, Quarter Power

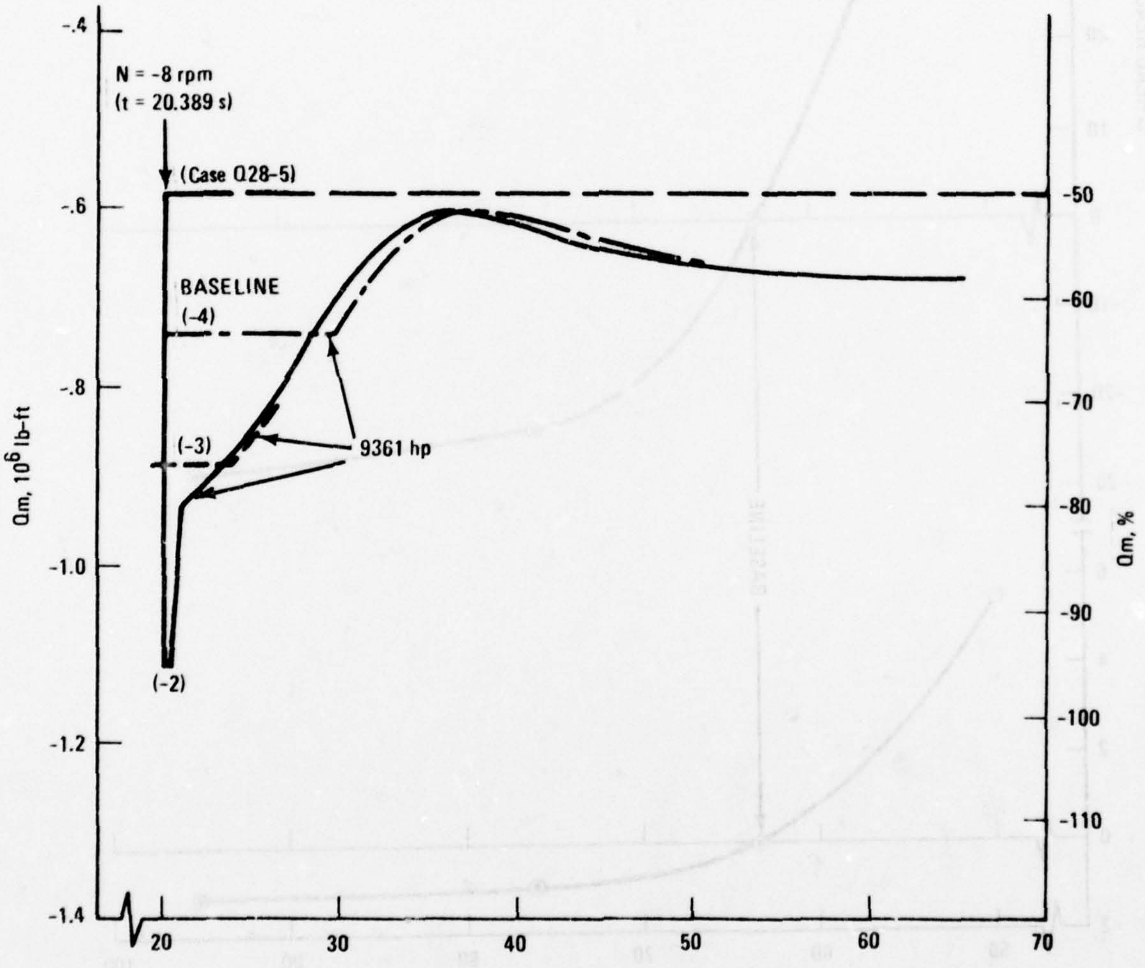


Figure 4-10a Propeller Reversed Qm Change, Quarter Power

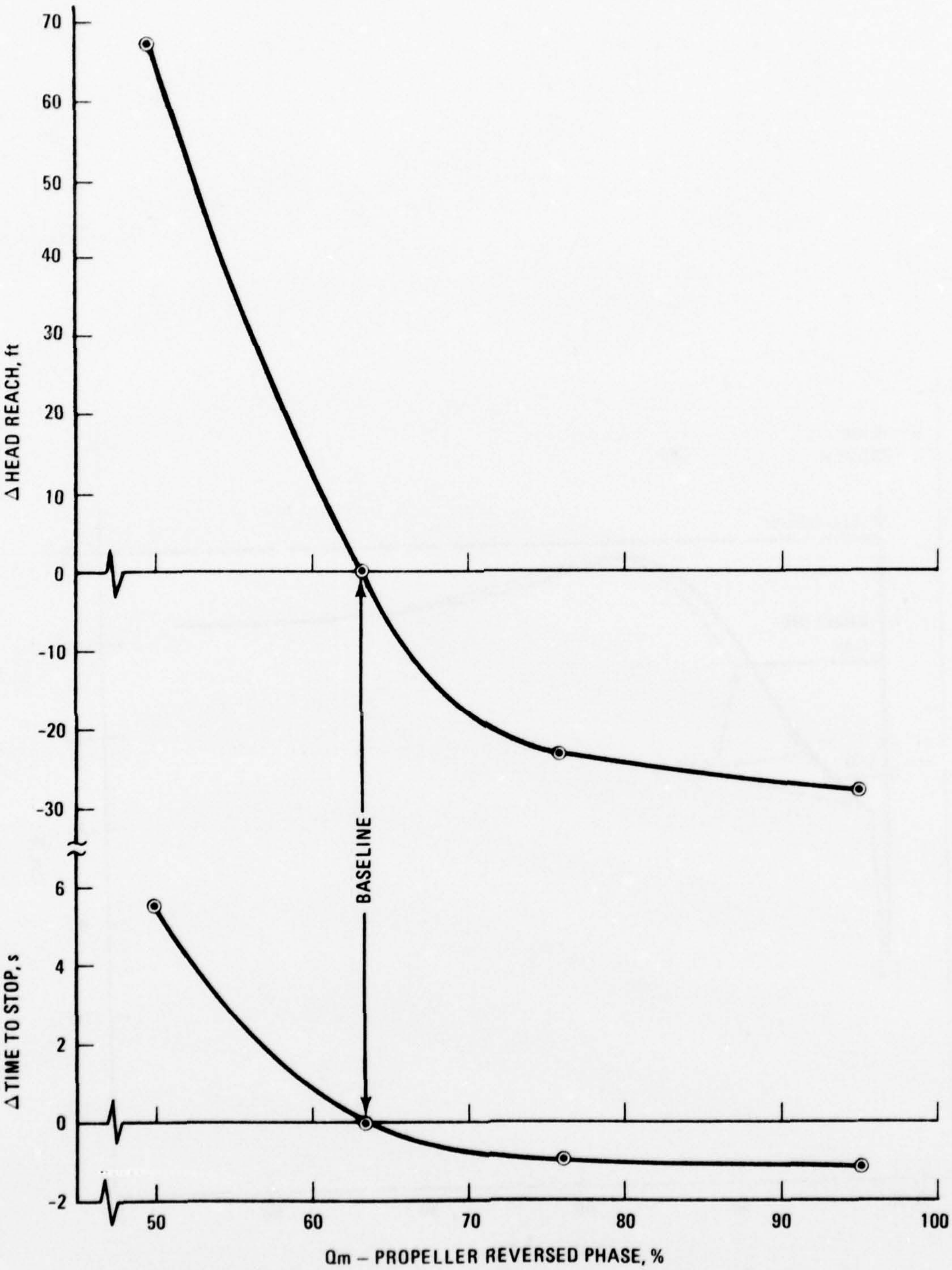


Figure 4-10b Propeller Reversed Qm Change, Quarter Power

Effect of changing the start of reversal

Four cases, Q33-1, Q31-2, Q30-1, and Q27-1 were run for comparison with the baseline case. Figure 4-11 shows the reversal characteristics, time to stop the ship, and head reach vs. the ship speed at which reversal is initiated.

Case Summary

A summary listing for the 12 quarter power crash back cases is shown in Table 4-5. Table 4-6 lists some typical torque values and gives the corresponding component currents.

Table 4-6. Component Currents, Quarter Power Configuration

Qm		component current, % of rated current	
%	lb-ft	motor	generator
95	1.112×10^6	95	150
76	0.890×10^6	76	120
63.3	0.742×10^6	63.3	100
50	0.585×10^6	50	78.9

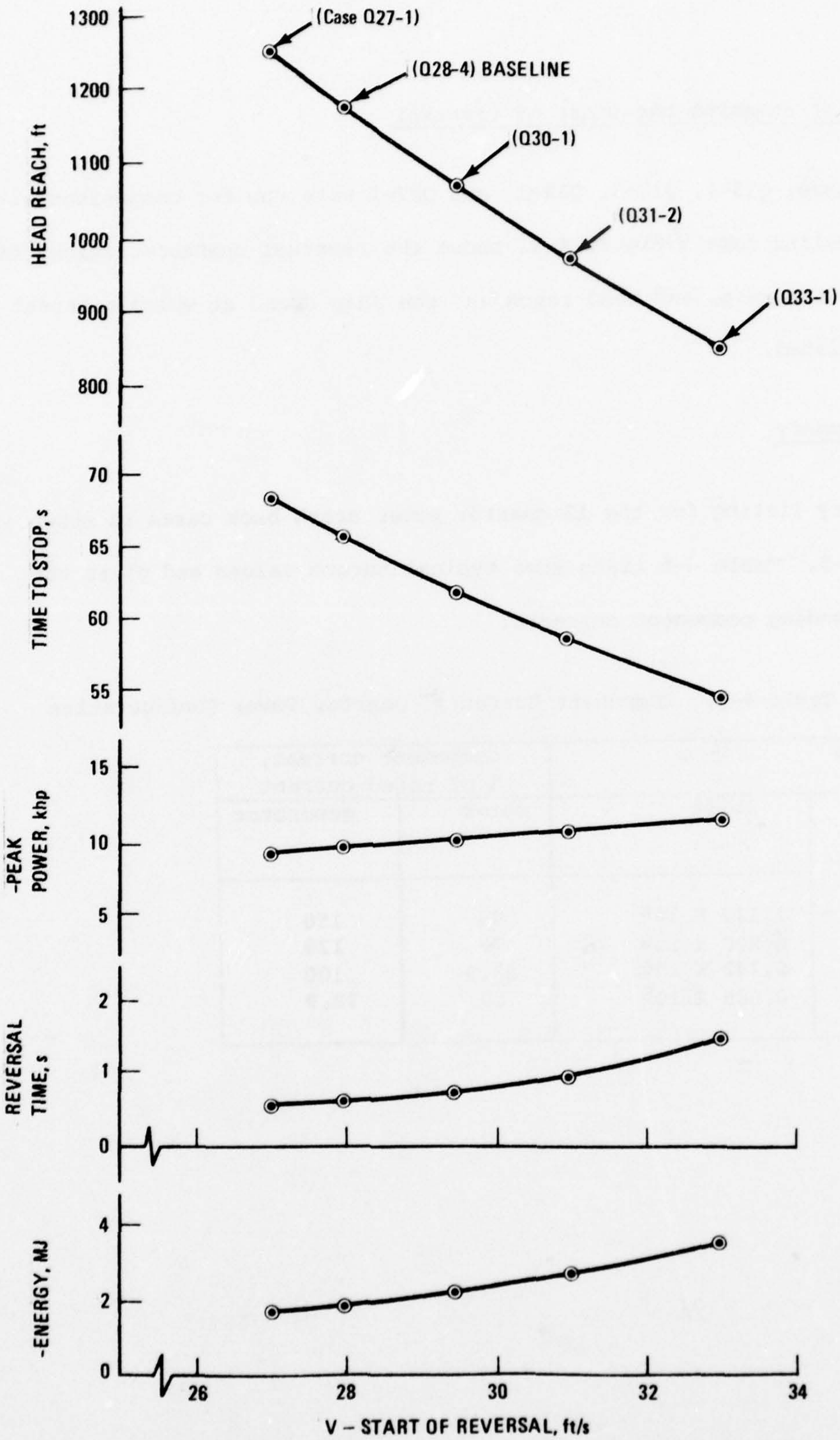


Figure 4-11 Start of Reversal Change, Quarter Power

Table 4-5 Constant Torque Quarter Power Crash Back Summary

all cases:	windmill down:	t, s	S, ft	V, ft/s	N, rpm	Qm, %	Pm, hp
	start	0	0	34.02	105.8	39.7	9361
	end	3	102	33.48	75	↗ 0	↗ 0

case	reversal						propeller reversed		total	head
	start		Qm,	total		peak	N=0→	N=-8→	time	reach,
	V,	t,		energy,	time,	power,	-8 rpm	V=0	to stop,	
	ft/s	s	%	MJ	s	hp	Qm, %	Qm, %	s	ft
Q33-1	33	4.285	-76 constant	3.529	1.453	11,745	-76	-63.3*	54.8	859
Q31-1	31	9.832	-95	2.285	0.567	13,707	-95	-63.3*	58.5	977
-2			-76	2.640	0.961	10,971	-76	-63.3*	58.6	979
-3			-63.3	3.491	2.079	9,146	-63.3	-63.3*	58.7	982
Q30-1	29.5	14.[illegible]	-76	2.215	0.774	10,440	-76	-63.3*	61.8	1075
Q28-1	28	19.631	-95	1.728	0.441	12,381	-95	-63.3*	65.4	1178
-2			-76	1.881	0.651	9,909	-76	-95*	64.3	1151
-3								-76*	64.4	1156
-4								-63.3*	65.4	1180
-5								-50	70.9	1247
-6			-63.3	2.113	0.997	8,261	-63.3	-63.3*	65.5	1182
Q27-1	27	23.381	-76	1.694	0.589	9,555	-76	-63.3*	68.1	1254

* power limited (9361 hp)

4.4 Reduced Power Levels

For each of the three baseline cases, the crash back was simulated by starting the maneuver at reduced power levels. The full power configuration was run starting at the half power, quarter power and cruise operating points (cases FH, FQ, and FC). The half power configuration was run at the quarter power and cruise operating points (cases HQ and HC) and the quarter power configuration was run at the cruise operating point (case QC).

Figure 4-12 shows a plot of time to stop the ship and head reach vs. ship speed at the start of the crash back maneuver.

A summary listing for these six cases is shown in Table 4-7. Also included are the three baseline cases when starting the crash back maneuver from their rated power points.

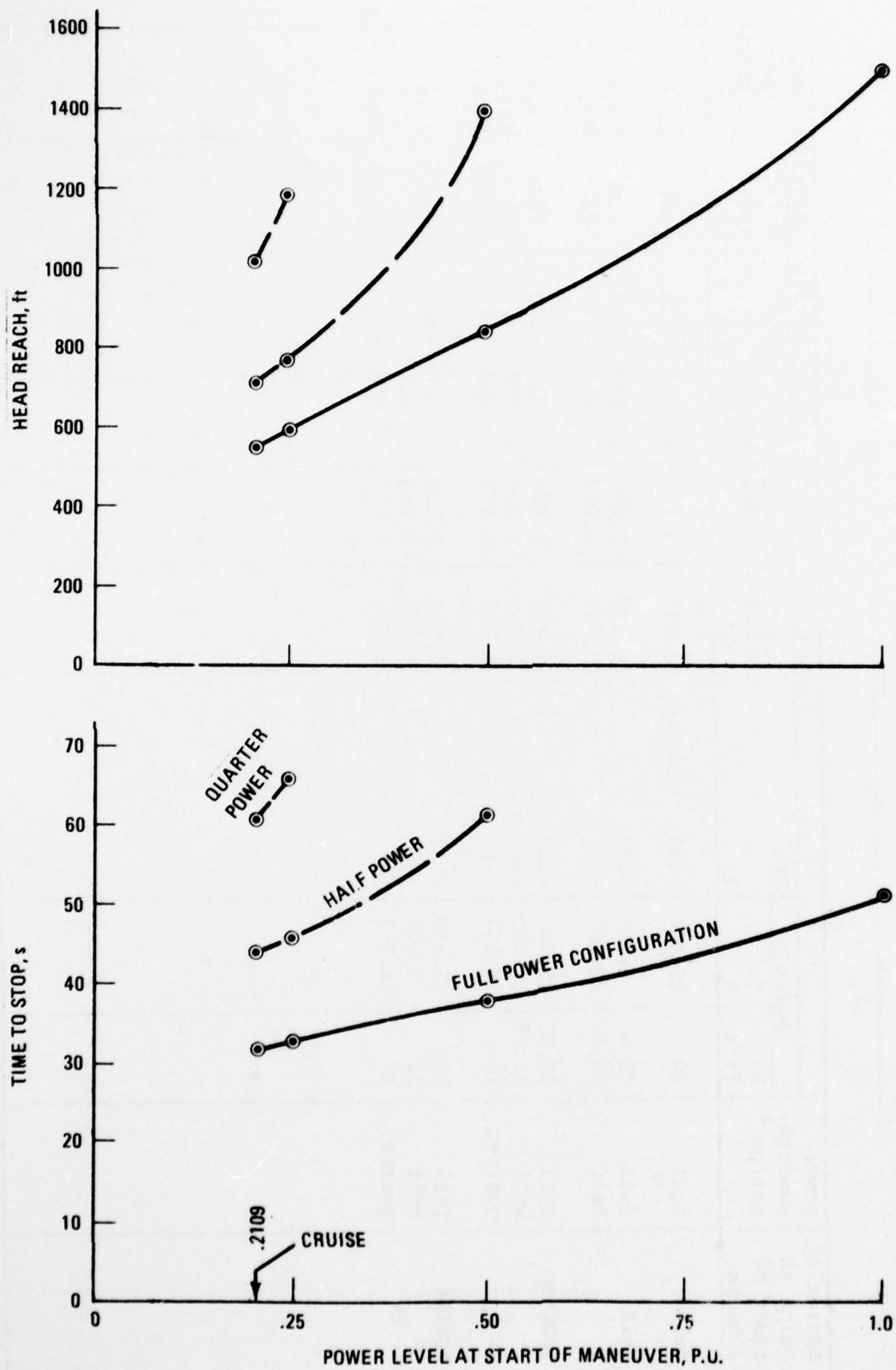


Figure 4-12 Crash Back Performance at Reduced Power Levels

Table 4-7 Reduced Power Level Crash Back Summary
and Baseline Crash Back Cases

cruise cases:

windmill down:	t, s	S, ft	V, ft/s	N, rpm	Qm, %	Pm, hp
start	0	0	32.15	100	35.4	7897
end	3	96	31.67	71	~ 0	~ 0

case	operating point at start of maneuver	power configu-ration	reversal						propeller reversed		total time to stop,	head reach,
			start		Qm,	total		peak	N=0→	N=-8→		
			V, ft/s	t, s	%	energy, MJ	time, s	power, hp	-8 rpm Qm, %	V=0 Qm, %	s	ft
F40-6	full	full	40	19.977	-120 constant	4.647	0.887	22,347	-120	-120	51.5	1507
FH	half	full	40	6.395	-120	4.646	0.888	22.348	-120	-120	37.9	837
H34-5		half	33.5	20.150	-76	3.831	1.662	11,855	-76	-76	61.1	1385
FQ	quarter	full	32.73	5.000	-120	2.427	0.429	18,310	-120	-120	32.4	586
HQ		half	32.73	5.000	-76	3.361	1.356	11,598	-76	-76	45.4	762
Q28-4		quarter	28	19.631	-76	1.881	0.651	9,909	-76	-63.3*	65.4	1180
FC	cruise	full	31	5.000	-120	2.104	0.380	17,347	-120	-120	31.4	544
HC		half	31	5.000	-76	2.645	0.960	10,989	-76	-76	43.9	706
QC		quarter	28	14.793	-76	1.881	0.651	9,909	-76	-63.3*	60.6	1016

* power limited
(9361 hp)

5. RAMPED TORQUE CASES

For the 13 ramped cases presented in this section, the ship/propulsion system is initially operating at rated conditions for the respective power configuration. The windmill down phase is the same as that for the corresponding constant torque cases. Thus, for instance, the simulation results for full power cases F45-1 through F45-6 (constant torque) and F45-1R (ramped torque) are identical from t=0 s up to the start of reversal at t=12.1 s.

For these cases the motor torque has some small initial value at the start of reversal and increases to a large value at the end. The purpose being to keep the difference between the motor and propeller torques fairly constant, and thereby, achieving a uniform deceleration rate of the propeller shaft. This type of characteristic simulates how reacceleration of the turbine-generator and/or a mechanical brake on the generator shaft might operate.

At the end of this section is a listing of the main features of the full power, half power, and quarter power ramped torque cases.

Full Power

Four cases, F40-1R, F40-2R, F40-3R, and F40-4R, were run with the initiation of the reversal phase starting at a ship speed of 40 ft/s. In all cases, the motor torque after the propeller speed had attained -8 rpm is -120 percent. The maximum differences between the time to stop the ship and head reach for the four cases are small, being 0.5 seconds and 21 ft respectively.

Figure 5-1 shows a plot of the motor and propeller torques, energy, motor power and propeller speed vs. time during the reversal phase for cases F40-1R and F40-4R.

One ramped case, F45-1R, was run with reversal starting at a ship speed of 45 ft/s. Pertinent details are given at the end of this section.

Half Power

One case, H37-1R, was run with the reversal phase starting at a ship speed of 37 ft/s. The motor and propeller torques, and the propeller speed during the reversal phase are shown in Figure 5-2.

Three cases, H34-1R, H34-2R, and H34-3R, were run with the reversal phase starting at a ship speed of 33.5 ft/s. In all cases, the motor torque is -76 percent after the propeller speed has attained a value of -8 rpm. Figure 5-3 shows the motor and propeller torques, energy, motor power, and propeller speed vs. time during the reversal phase for case, H34-1R.

Quarter Power

One case, Q31-1R, was run with the reversal phase starting at a ship speed of 31 ft/s. The motor and propeller torques, and propeller speed are shown in Figure 5-4 during the reversal phase.

Three cases, Q28-1R, Q28-2R, and Q28-3R, were run with the reversal phase starting at a ship speed of 28 ft/s. In all cases, the motor torque is -63.3 percent after the propeller speed has attained a value of -8 rpm.

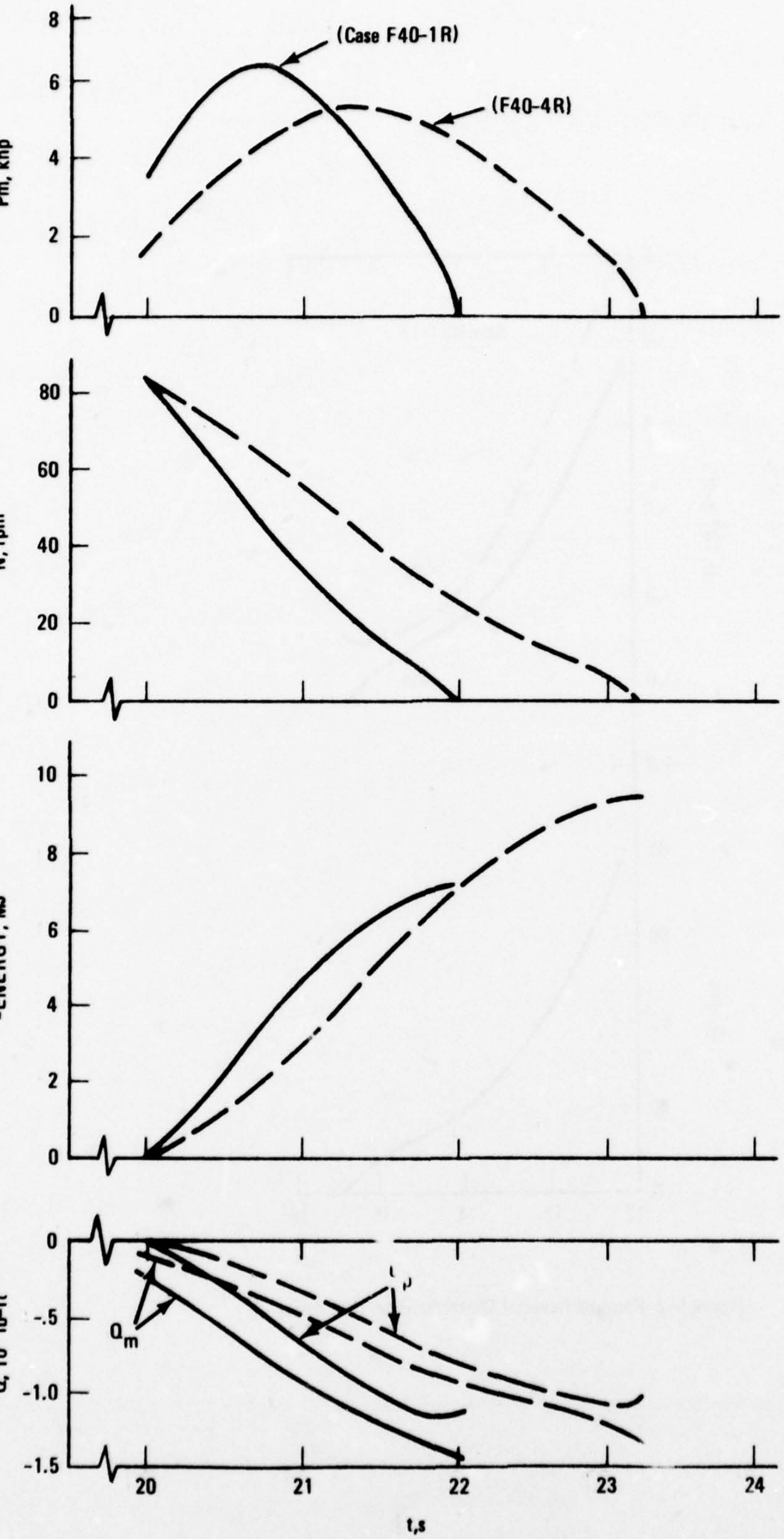


Figure 5-1 Ramped Reversal Characteristics, Full Power

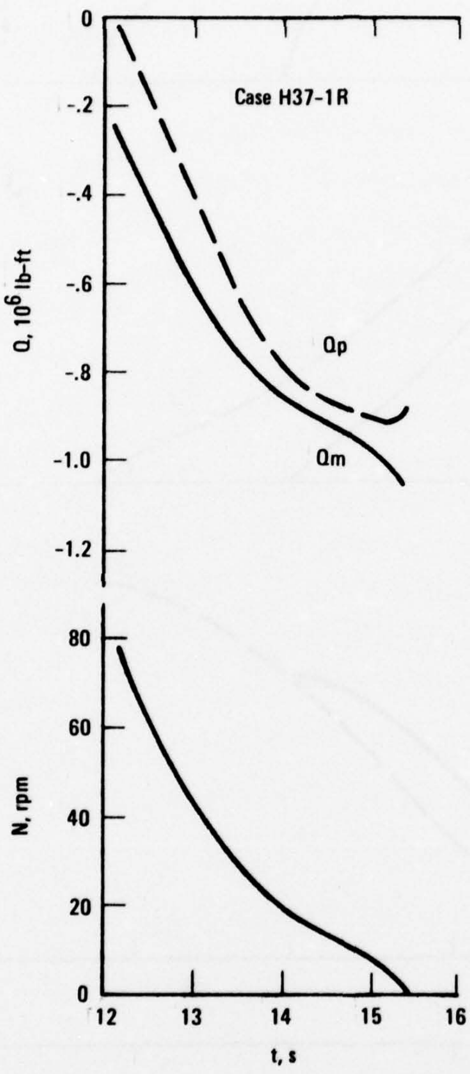


Figure 5-2 Ramped Reversal Characteristics, Half Power

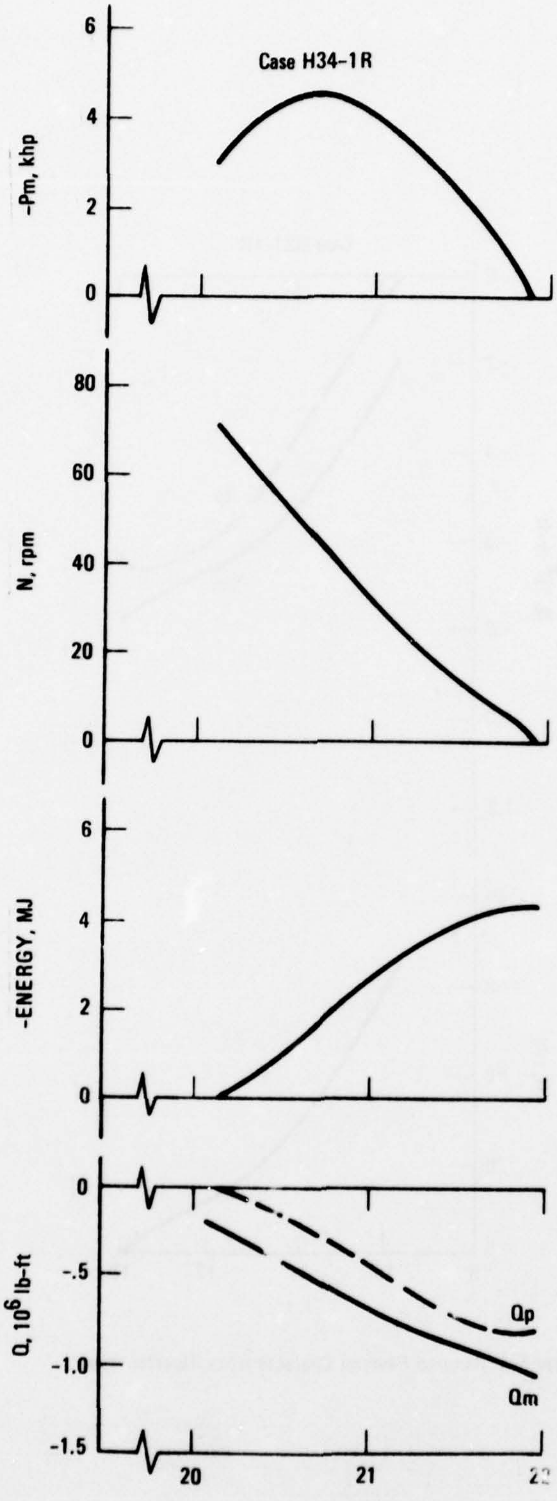


Figure 5-3 Ramped Reversal Characteristics, Half Power

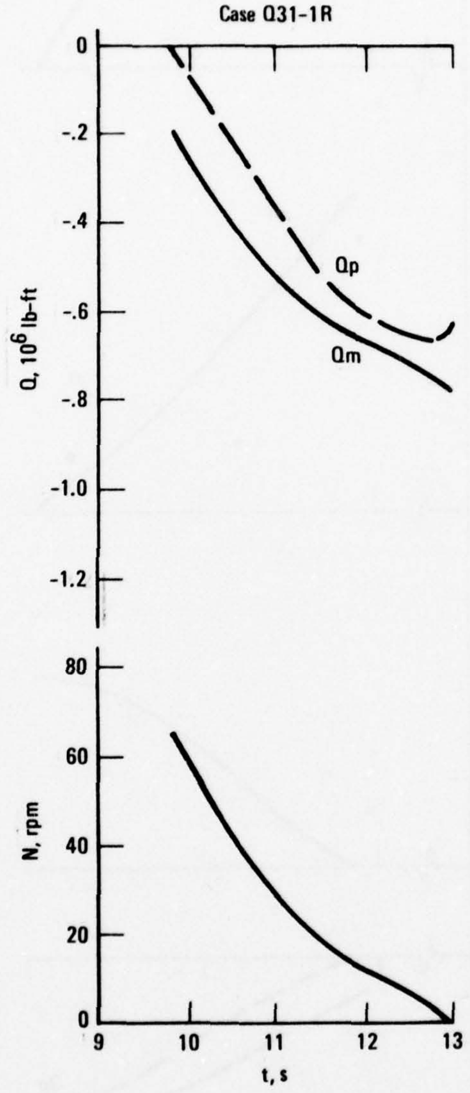


Figure 5-4 Ramped Reversal Characteristics, Quarter Power

Figure 5-5 shows the motor and propeller torques, energy, motor power, and propeller speed vs. time during the reversal phase for case Q28-1R.

Case Summary

A summary listing for the 13 ramped torque cases is shown in Table 5-1. Although the table format is almost identical to the previous summary tables, it is pointed out that one column (N_{TG} at end) has been added. This column is discussed below.

The values shown give the turbine-generator speed at the end of reversal under the conditions that all of the energy generated during reversal is stored and none is dissipated (e.g. in a mechanical brake). As discussed in section 2.2, it is assumed that the speed at the beginning of the reversal phase is 1800 rpm. Also, in the full, half, and quarter power configurations, there are 2, 1, and 0.5 turbine generator sets respectively in which energy may be stored.

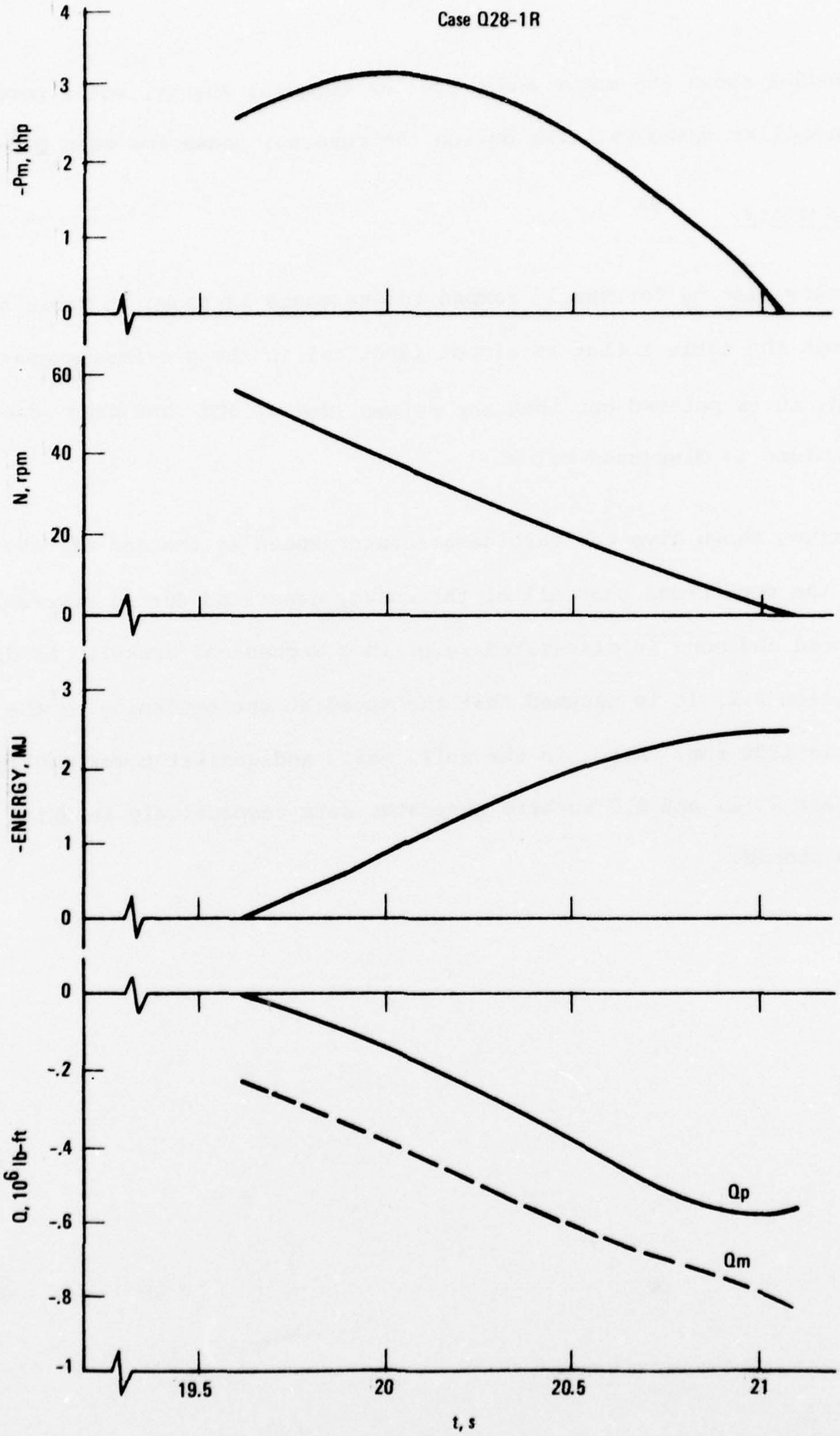


Figure 5-5 Ramped Reversal Characteristics, Quarter Power

Table 5-1 Ramped Torque Crash Back Summary

case	reversal								propeller reversed		total time to stop, s	head reach ft
	start		Qm, %		total		peak power, hp	N_{TG} at end, rpm	N=0→ -8 rpm Qm, %	N=-8→ V=0 Qm, %		
	V, ft/s	t, s			energy, MJ	time, s						
F45-1R	45	12.100	-15/-140	ramp	11.834	2.771	8,204	3292	-140	-120	46.8	1308
F40-1R	40	19.977	-20/-120		7.299	2.069	6,697	2815	-120	-120	52.1	1529
-2R			-16/-116		8.089	2.466	6,256	2904	-116	-120	52.2	1535
-3R			-13/-113		8.804	2.839	5,938	2982	-113	-120	52.4	1542
-4R			-10/-110		9.631	3.300	5,631	3069	-110	-120	52.6	1550
H37-1R	37	12.142	-20/-90.5	ramp	[illegible].064	3.297	4,997	3687	-90.5	-76	56.2	1213
H34-1R	33.5	20.150	-20/-90.5	ramp	4.275	1.850	4,529	2954	-90.5	-76	61.4	1395
-2R			-16/-86.5		4.765	2.178	4,136	3059	-86.5	-76	61.6	1399
-3R			-13/-83.5		5.255	2.589	3,855	3160	-83.5	-76	61.7	1404
Q31-1R	31	9.832	-16/-66.4	ramp	4.938	3.208	3,148	3990	-66.4	-63.3*	59.3	1000
Q28-1R	28	19.631	-20/-70.4	ramp	2.497	1.454	3,195	3107	-70.4	-63.3*	65.8	1190
-2R			-16/-66.4		2.751	1.802	2,842	3210	-66.4	-63.3*	65.9	1194
-3R			-13/-63.3		3.022	2.179	2,593	3316	-63.3	-63.3*	66.1	1198

* power limited
(9361 hp)

6. SAW-TOOTH TORQUE CASES

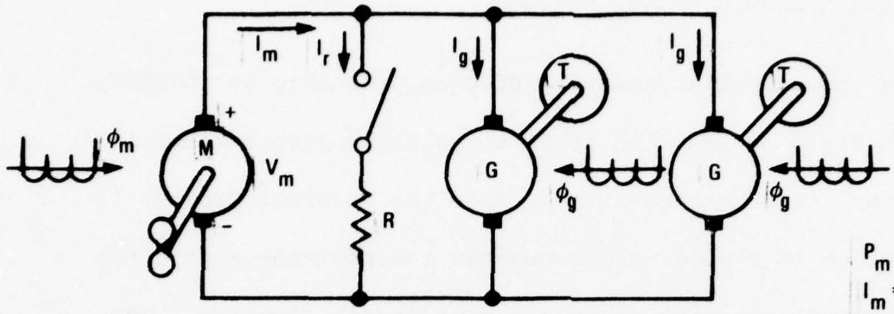
Twenty-five cases were run which simulate the use of a (shunt) dynamic resistor plus reacceleration of the T-G (turbine generator) set(s) for dissipating and storing the energy generated during the propeller reversal process. The cases are divided into two major categories: full motor field and motor field weakening. Single stage dynamic resistor cases were run for both categories, however, multistage resistors were only simulated for full motor field.

At the end of this section is a summary listing for all of the cases which are arranged by dash number (rather than by power configuration) since, for a given dash number, the value of resistance(s) is/are the same for all configurations.

Circuits

For this analysis, the circuits shown in Figure 6-1 were used. The motor, line, and generator resistances and inductances are neglected. The dynamic resistor is connected across the motor terminals.

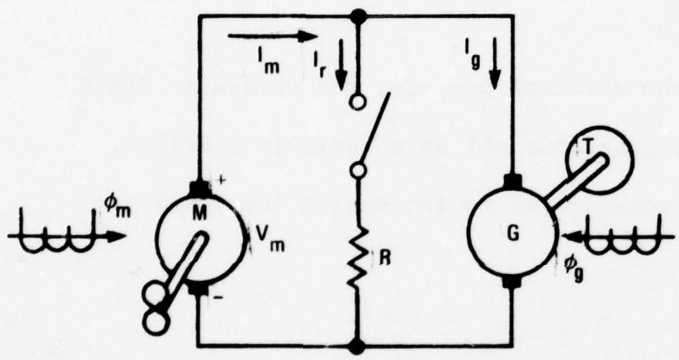
When a component absorbs electrical power, the power (P) and energy (U) are taken to be positive quantities. Thus, during the reversal process, the power and energy are negative for the motor and positive for the resistor and generator.



$$P_m + P_r + 2P_g = 0$$
$$I_m = I_r + 2I_g$$

$$P_m = -I_m V_m$$
$$P_r = I_r V_m$$
$$P_g = I_g V_m$$

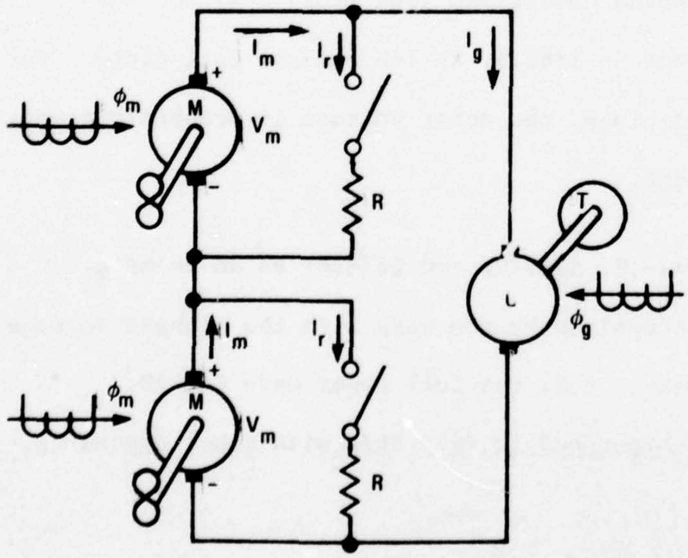
a) Full Power Configuration



$$P_m + P_r + P_g = 0$$
$$I_m = I_r + I_g$$

$$P_m = -I_m V_m$$
$$P_r = I_r V_m$$
$$P_g = I_g V_m$$

b) Half Power Configuration



$$P_m + P_r + 1/2P_g = 0$$
$$I_m = I_r + I_g$$

$$P_m = -I_m V_m$$
$$P_r = I_r V_m$$
$$P_g = I_g V_m \times 2$$

c) Quarter Power Configuration

Figure 6-1 Circuit Diagrams

General Description of the Reversal Process

Prior to starting the propeller reversal process, the ship is shooting and the generator field is adjusted so as to maintain zero current in the motor-generator armature circuit(s). When the reversal process is initiated, the switch is closed which connects the resistor across the motor terminals thus dissipating energy in the dynamic resistor. The generator field continues to be controlled in such a manner that the generator current remains zero.

At a preselected point during the reversal process, the generator field is controlled so as to make the generator act as a variable resistor. The absorbed energy is stored mechanically by increasing the speed of the rotating T-G mass(es).

Resistor Sizing

Based upon the full power operating conditions (see Table 2-1) for the lossless motor, the motor voltage is 1862.9V at 168 rpm and full field. For any other set of operating conditions, the motor voltage is proportional to the motor speed and field current.

Taking the set of -1S cases (F47-1S, H37-1S, and Q33-1S) as an example, the single stage resistor is determined by the case with the highest voltage at the start of the reversal phase, i.e. the full power case F47-1S. At the start of reversal, the ship speed is 46.9 ft/s with a corresponding

propeller speed of 97.94 rpm. Since the motor field is not weakened for these cases, the motor terminal voltage at this point is:

$$Vm = 97.94 \text{ rpm } \frac{1862.9 \text{ V}}{168 \text{ rpm}} = 1086.1 \text{ V}$$

The resistor is then sized to limit the motor current to 150 percent of its rated current, or:

$$R = \frac{1086.1 \text{ V}}{1.5 \text{ X } 15000 \text{ A}} = 0.0483 \, \Omega$$

In the half power configuration case, H37-1S, the propeller speed at the beginning of the reversal phase is 77.27 rpm which results in an initial current of 17751 A. At first, this may appear to violate the current limitation of 14250 A for the half power configuration, however, this current passes through the motor and dynamic resistor only. The generator current remains zero until near the end of the reversal process. At stall, all of the motor current passes through the generator and the current must be limited to 150 percent of rated generator current (14250 A).

6.1 Full Motor Field

Seven sets of cases are presented. The first four (-1S through -4S) assume the use of a single stage resistor and simulation results are given for a full, half, and quarter power crash back. The -5S cases were also run for all three configurations, but a two stage resistor was used.

The last two sets (F45-6S and F40-7S) consist of one case apiece for a full power crash back with a four stage resistor.

R= 0.0483 Ohm

Three -1S cases, one for each power configuration, were run where the reversal process was simulated by assuming a single stage resistor. The resistor was sized to limit the motor current to 150 percent of its rated value in the full power crash back case, F47-1S.

Figure 6-2 shows the propeller speed, propeller torque, motor torque, motor power, and energy generated by the motor as functions of time for the full (F47-1S), half (H37-1S), and quarter (Q33-1S) power configurations. The time intervals shown are for the reversal process only.

As the reversal process proceeds, the propeller slows down thus reducing the motor voltage, current, and torque. At a preselected propeller speed, the generator starts functioning as a variable resistor in such a manner that the motor torque increases up to a limiting value.

For these three cases, the stored energy is between 25 percent (quarter power) and 31 percent (full power) of the total energy generated during the reversal process.

R= 0.0463 Ohm

The -2S cases (Figure 6-3) are very similar to the previously described -1S cases. The difference lies in the slightly lower resistance value

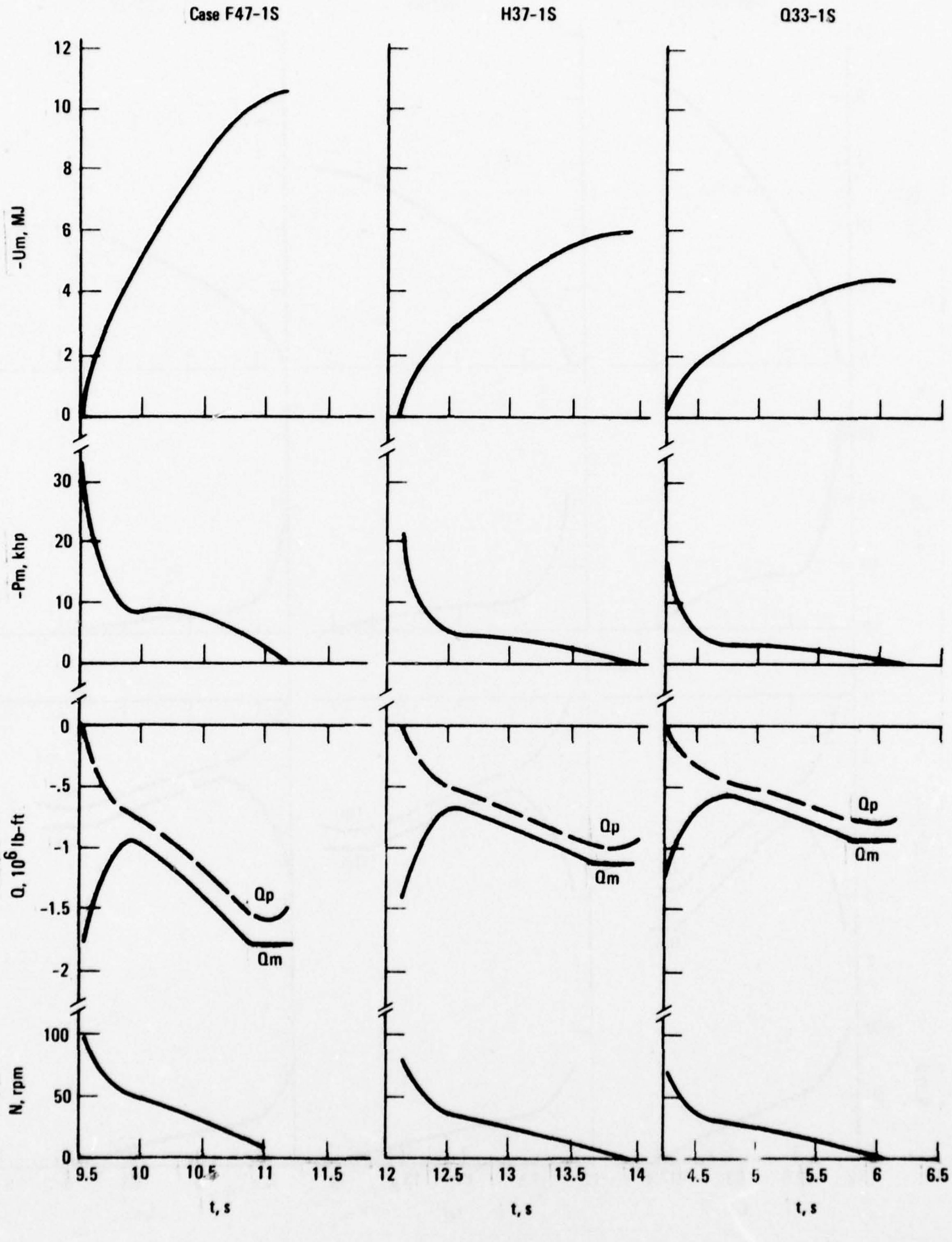


Figure 6-2 R = 0.0483 Ohm

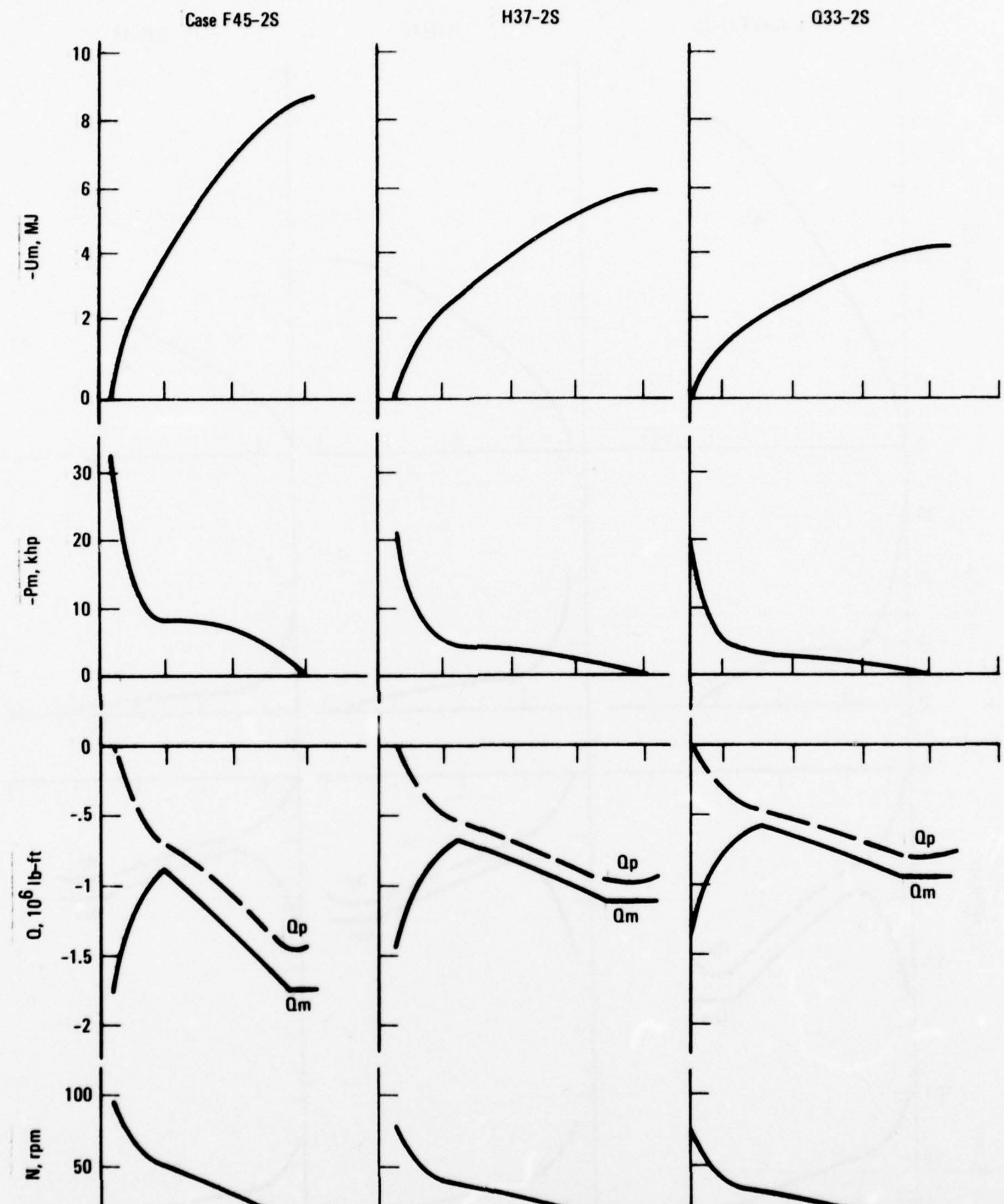


Figure 6-3 R = 0.0463 Ohm

which was sized for starting the reversal process at a speed of 45 ft/s in the full power configuration.

Figure 6-4 and Table 6-1 show the reversal process characteristics in more detail for the full power configuration.

> NOTE: At the end of the reversal process, the stored energy on a half ship basis is 2xUg=2.380 MJ (Table 6-1). The summary table (Table 6-4) at the end of this section gives a value of 2.604 MJ. This difference lies in the application of the approximate method used to calculate the breakdown between the energy dissipated and the energy stored. For the summary table value, only one interval (t=12.465 s to 13.538 s) was used. For Table 6-1, five intervals were used, and therefore, it gives a more accurate estimate for the energy distribution.

R= 0.0432 Ohm (and 0.0208 Ohm)

This value of resistance was sized for starting the reversal process in the full power configuration at a ship speed of 42 ft/s. Three sets of cases (-3S, -4S, and -5S) were run for each configuration. The differences between the three sets are in the motor torque profile after the 0.0432 ohm resistor has slowed the propeller to about half of the windmilling speed.

Figure 6-5 shows the -3S, -4S, and -5S torque and propeller speed characteristics for the full power configuration. Figures 6-6 and 6-7 show the characteristics for the half and quarter power configurations.

The -3S cases are similar to the -1S and -2S cases. At a preselected propeller speed the motor torque is ramped linearly with propeller speed.

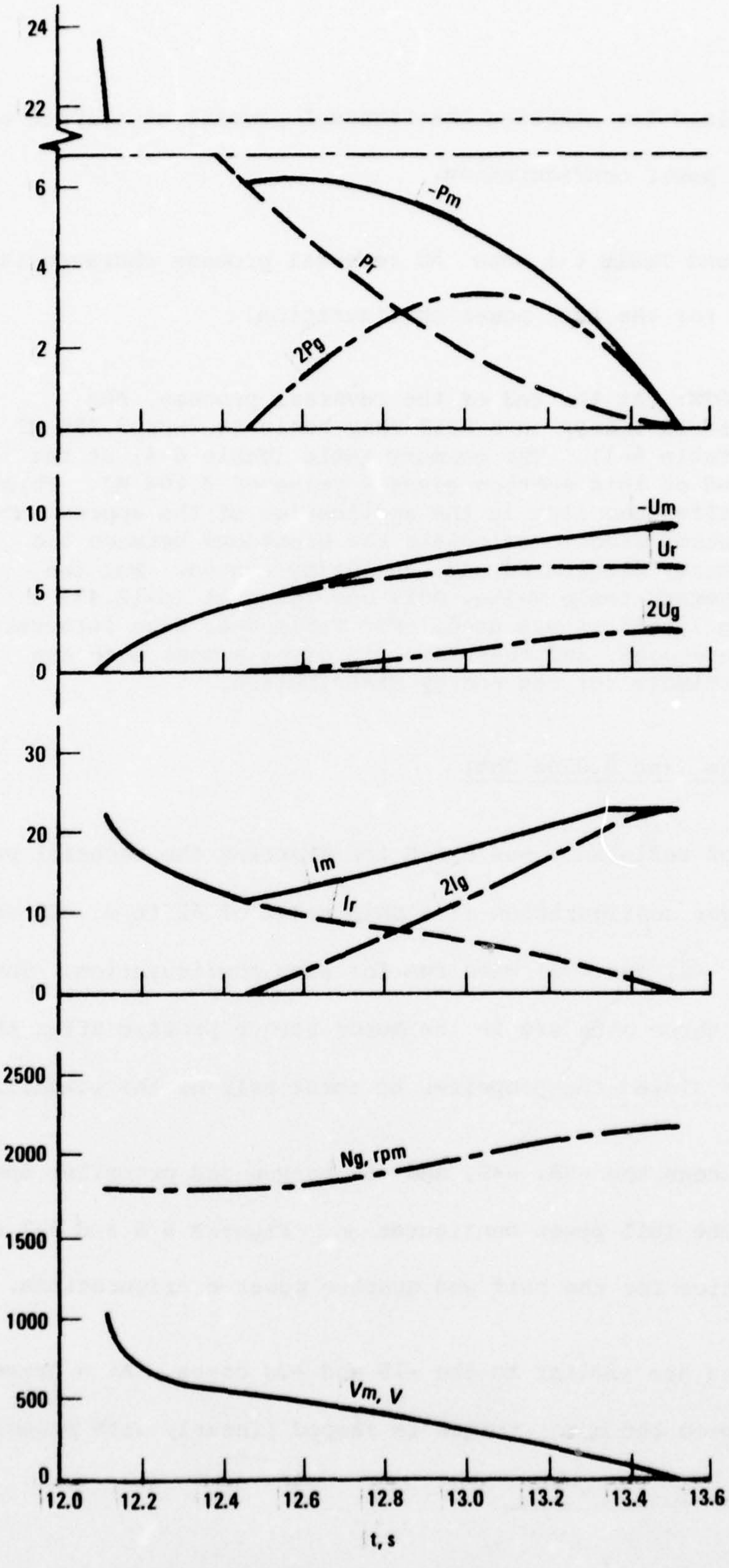


Figure 6-4 Reversal Process for Case F45-2S, R = 0.0463 Ohm

Table 6-1 Reversal Process Summary for Case F45-2S, R=0.0463 Ohm

profile program								
t, s	12.100	12.250	12.465	12.700	12.900	13.100	13.364	13.538
N, rpm	93.98	62.76	47.69	39.01	30.70	21.76	9.35	0.0
Qm, 10^6 lb-ft	-1.757	-1.178	-0.892	-1.088	-1.275	-1.477	-1.757	-1.757
Qp, 10^6 lb-ft	0.008	-0.445	-0.704	-0.863	-1.027	-1.222	-1.435	-1.405
Pm, hp	-31,440	-14,080	-8100	-8080	-7454	-6119	-3128	0
kW	-23,445	-10.499	-6040	-6025	-5558	-4563	-2333	0
Um, MJ	0.0	-2.353	-4.000	-5.430	-6.596	-7.617	-8.560	-8.765
Δt, s	-	0.150	0.215	0.235	0.200	0.200	0.264	0.174
Δ Um, MJ	-	-2.353	-1.647	-1.430	-1.16	-1.021	-0.943	-0.205
motor								
Vm, V	1042.1	695.9	528.8	432.6	340.4	241.3	103.7	0
Im, A	22,506	15,090	11,426	13,937	16,332	18,920	22,506	22,506
resistor								
I_r, A	22,506	15,090	11,426	9339	7349	5209	2239	0
P_r, kW	23,445	10,499	6040	4040	2501	1257	232	0
ΔU_r, MJ		2.353	1.647	1.176	0.648	0.369	0.179	0.013
U_r, MJ		2.353	4.000	5.176	5.825	6.194	6.372	6.386
per T-G Set								
Ig, A	0	0	0	2299	4492	6856	10,134	11,253
Pg, kW	0	0	0	993	1529	1653	1051	0
ΔUg, MJ	0	0	0	0.127	0.259	0.326	.382	0.096
Ug, MJ	0	0	0	0.127	0.386	0.712	1.094	1.190
Ng, rpm	1800	1800	1800	1845	1933	2038	2155	2183

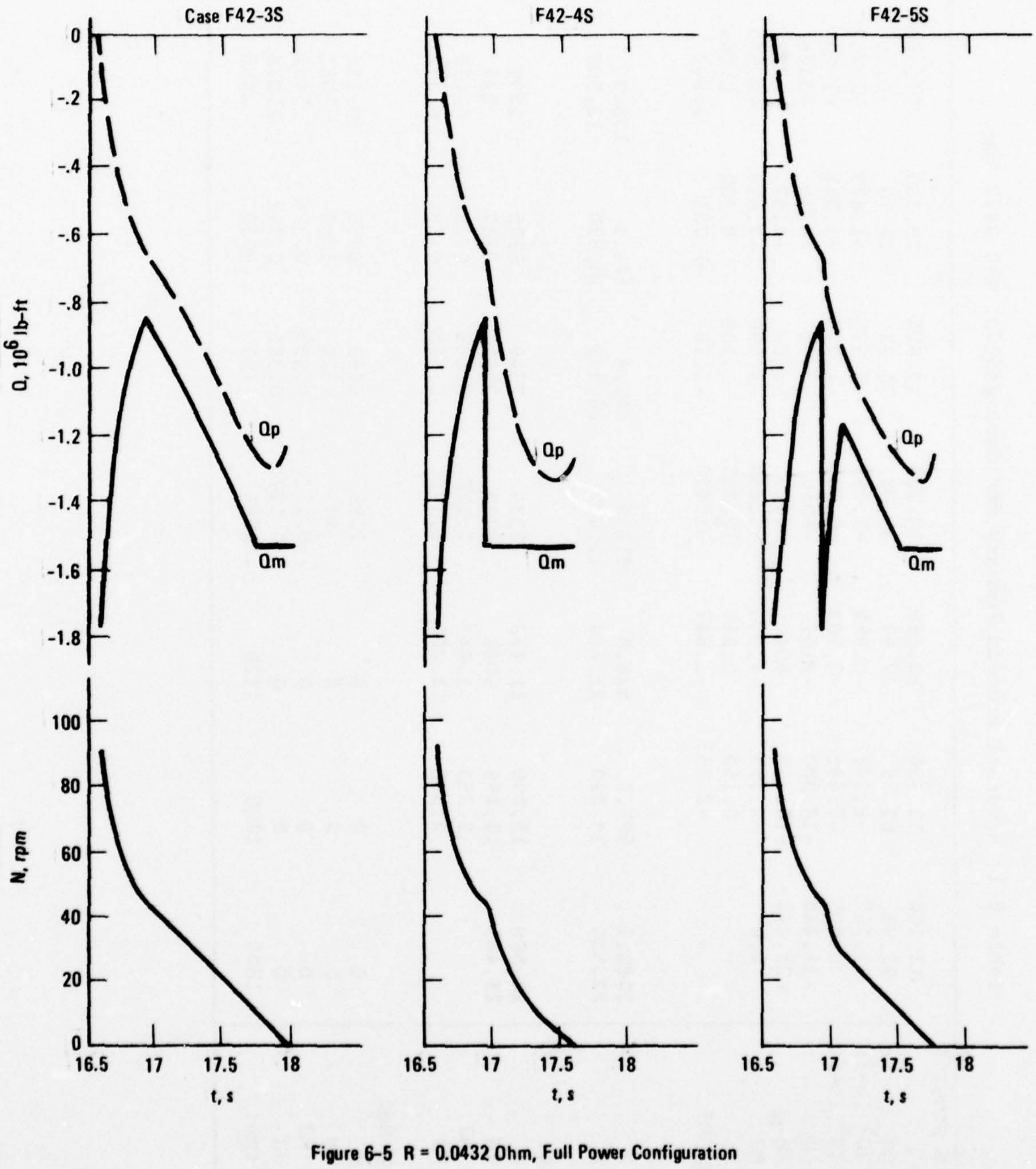


Figure 6-5 R = 0.0432 Ohm, Full Power Configuration

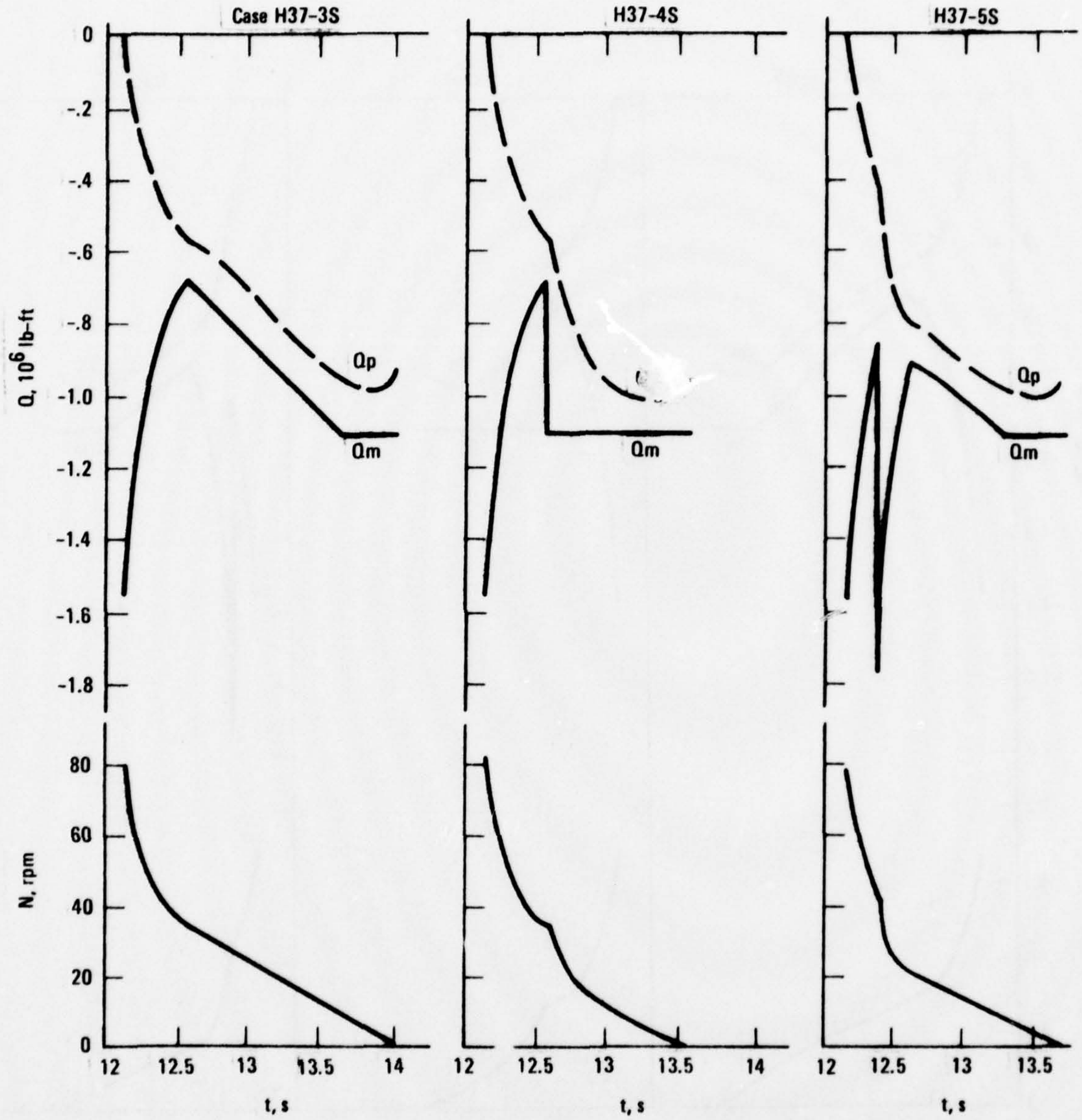


Figure 6-6 R = 0.0432 Ohm, Half Power Configuration

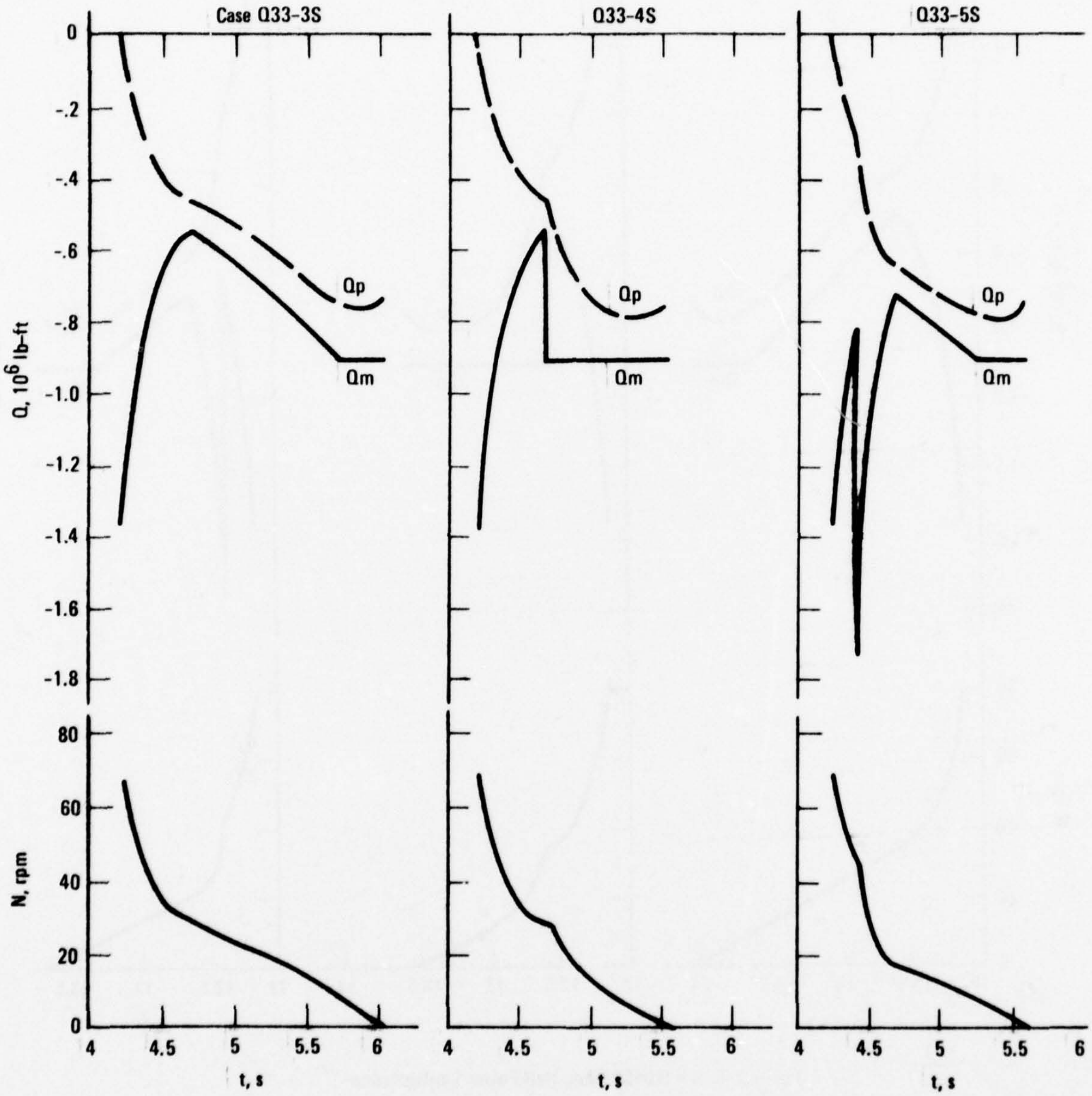


Figure 6-7 R = 0.0432 Ohm, Quarter Power Configuration

For the -4S cases, after the initial propeller deceleration with the 0.0432 ohm resistor, the motor torque is stepped and then held constant. This characteristic could be achieved by controlling the generator field to maintain a constant motor current.

A two stage dynamic resistor was used for the -5S cases. The combined resistance of the first stage (0.0432 ohm) and second stage (0.0401 ohm) in parallel is 0.0208 ohm. A short time after the second stage has been switched into the circuit, the motor torque profile is ramped up in a manner similar to the -3S cases. Comparing the -5S cases with the -3S cases, the use of a two stage resistor reduces the stored energy by about 30 percent.

Four Stage Resistor

Two full power cases were run which simulated the use of a four stage dynamic resistor. One started the reversal process at 45 ft/s (F45-6S) and the other at 40 ft/s (F40-7S).

Figure 6-8 shows the motor torque, propeller torque, propeller speed, motor power, and energy generated during the reversal process for case F40-7S. A tabulation of the reversal characteristics for both cases is shown in Table 6-2.

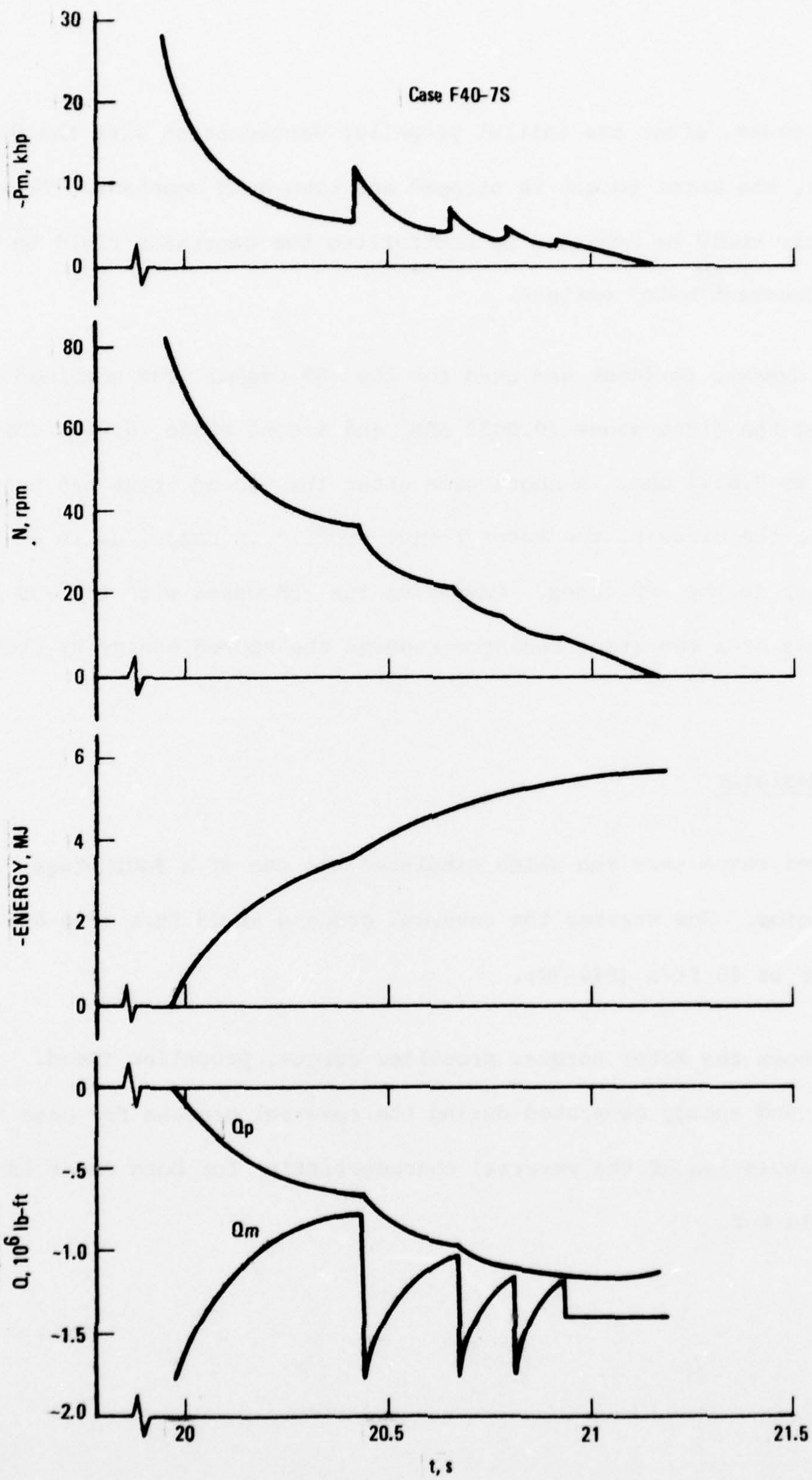


Figure 6-8 Saw Tooth Reversal Characteristics, Full Power

Table 6-2. Reversal Phase Characteristics for Four Stage Resistor Cases

Case	F45-6S					F40-7S				
Step	1	2	3	4	-	1	2	3	4	-
Time, s	0.477	0.207	0.179	0.084	0.495	0.463	0.234	0.137	0.126	0.233
N-start, rpm	93.98	45.00	30.00	22.00	18.00	83.54	36.00	21.00	14.00	9.50
N-end, rpm	45.00	30.00	22.00	18.00	0.0	36.00	21.00	14.00	9.50	0.0
Qm-start, 10^6 lb-ft	-1.757	-1.757	-1.757	-1.757	-1.639	-1.757	-1.757	-1.757	-1.757	-1.405
Qm-end, 10^6 lb-ft	-.841	-1.171	-1.288	-1.438	-1.639	-.667	-1.025	-1.171	-1.192	-1.405
Pm peak, hp	31,440	15,054	10,036	7,360	5617	27,946	12,043	7,025	4,683	2,541
Energy, MJ	4.636	1.423	0.899	0.364	0.968	3.633	1.069	0.432	0.263	0.222
R, ohm	0.0463	0.0222	0.0148	0.0108	-	0.0412	0.0177	0.0103	0.0069	-
Total time, s	1.442					1.193				
Total energy, MJ	8.290					5.619				

6.2 Field Weakening

One of the disadvantages with the resistor cases considered so far is the mismatch between the propeller and motor torque characteristics, i.e., at high propeller speeds the propeller torque is low and the motor torque is high, and at low propeller speeds this situation is reversed. A method for improving the motor torque characteristics when using a single stage resistor is to use a lower value of resistance and weaken the motor field during the initial part of the reversal process in order to stay within the motor current limitations.

Two sets of weakened motor field cases were run. Each set assumed the use of a single stage resistor. The first set of cases (-1W) uses a slightly larger resistor than the second set (-2W) which allows the full power crash back reversal process to be initiated at a higher ship speed.

R= 0.0216 Ohm

For the value of resistance selected for the -1W cases (0.0216 ohm), full motor field is first achieved at a propeller speed of 43.9 rpm. At speeds in excess of this value, the motor current is at the limit of 22,500 A, the power dissipated in the resistor is constant, and the motor torque and motor field are proportional to the reciprocal of the propeller speed. At speeds below 43.9 rpm, the motor field is at 1 p.u. and the motor torque varies linearly with propeller speed until such time that energy is stored in the T-G set(s).

Figure 6-9 shows the torque and propeller speed characteristics for the full power configuration with the reversal process starting at ship speeds of 46.9, 45, and 42 ft/s. Figure 6-10 shows the characteristics for the full power configuration (start of reversal at 42 ft/s), and the half and quarter power configurations.

Figure 6-11 and Table 6-3 show the reversal process in greater detail for the full power configuration when starting the propeller reversal process at a ship speed of 45 ft/s.

R= 0.0086 Ohm

For this very low value of resistance (0.0086 ohm), the motor field must be weakened considerably. Figure 6-12 shows the torque and propeller speed characteristics for the full power (start of reversal at 42 ft/s), half power, and quarter power configurations. At the start of reversal in the full power configuration, the motor field must be reduced to 0.20 p.u. in order to stay within the motor current limitation (22,500 A).

The stored energy for these cases (F42-2W, H37-2W, and Q33-2W) is very low and the change in the TG speed(s) is minimal being 29 rpm in the full power configuration and 69 rpm in the quarter power configuration (assuming an initial TG speed of 1800 rpm).

6.3 Case Summary

A summary listing for the 25 cases is shown in Table 6-4. An explanation is given in the notes which follow the table.

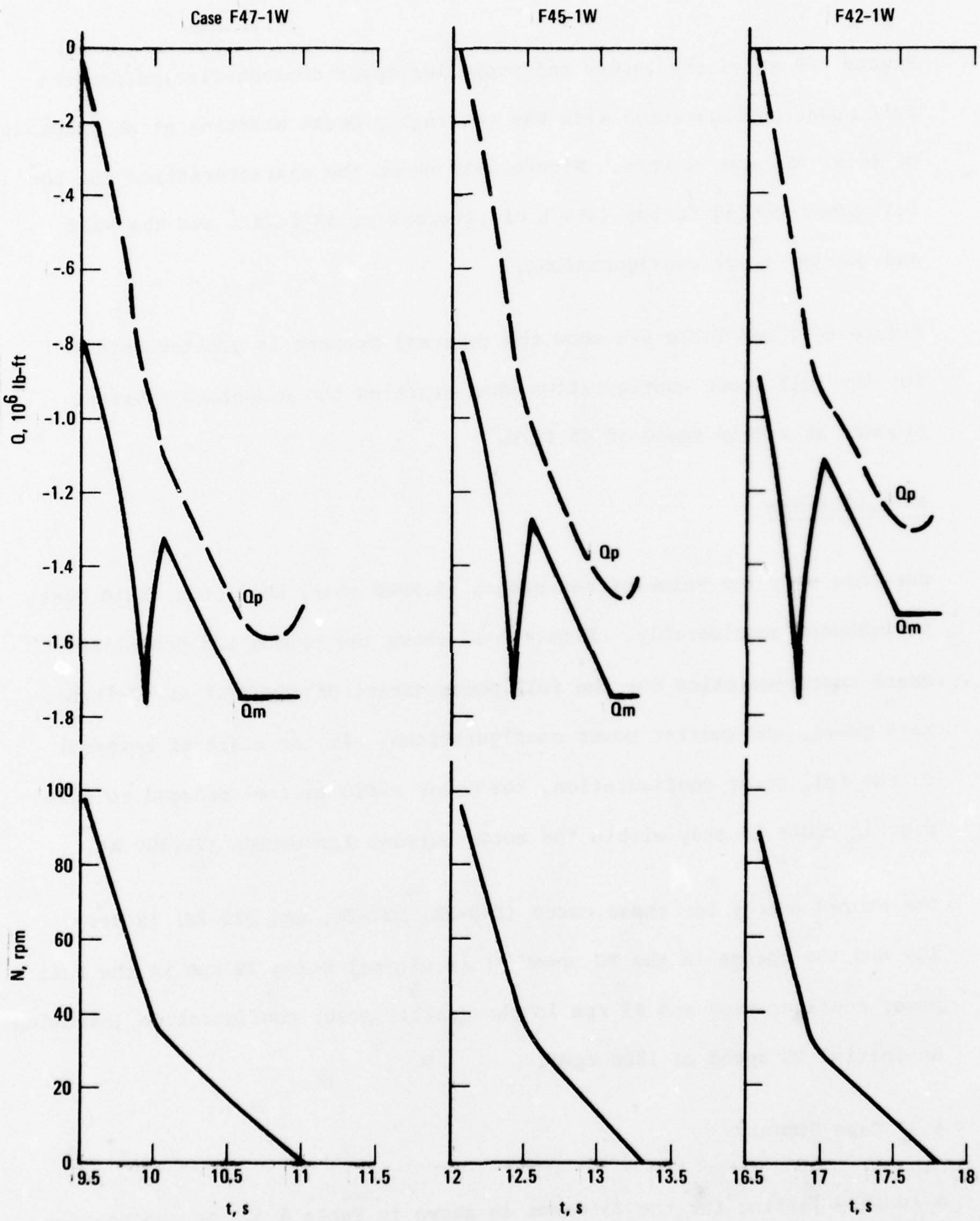


Figure 6-9 R = 0.0216 Ohm, Full Power Configuration

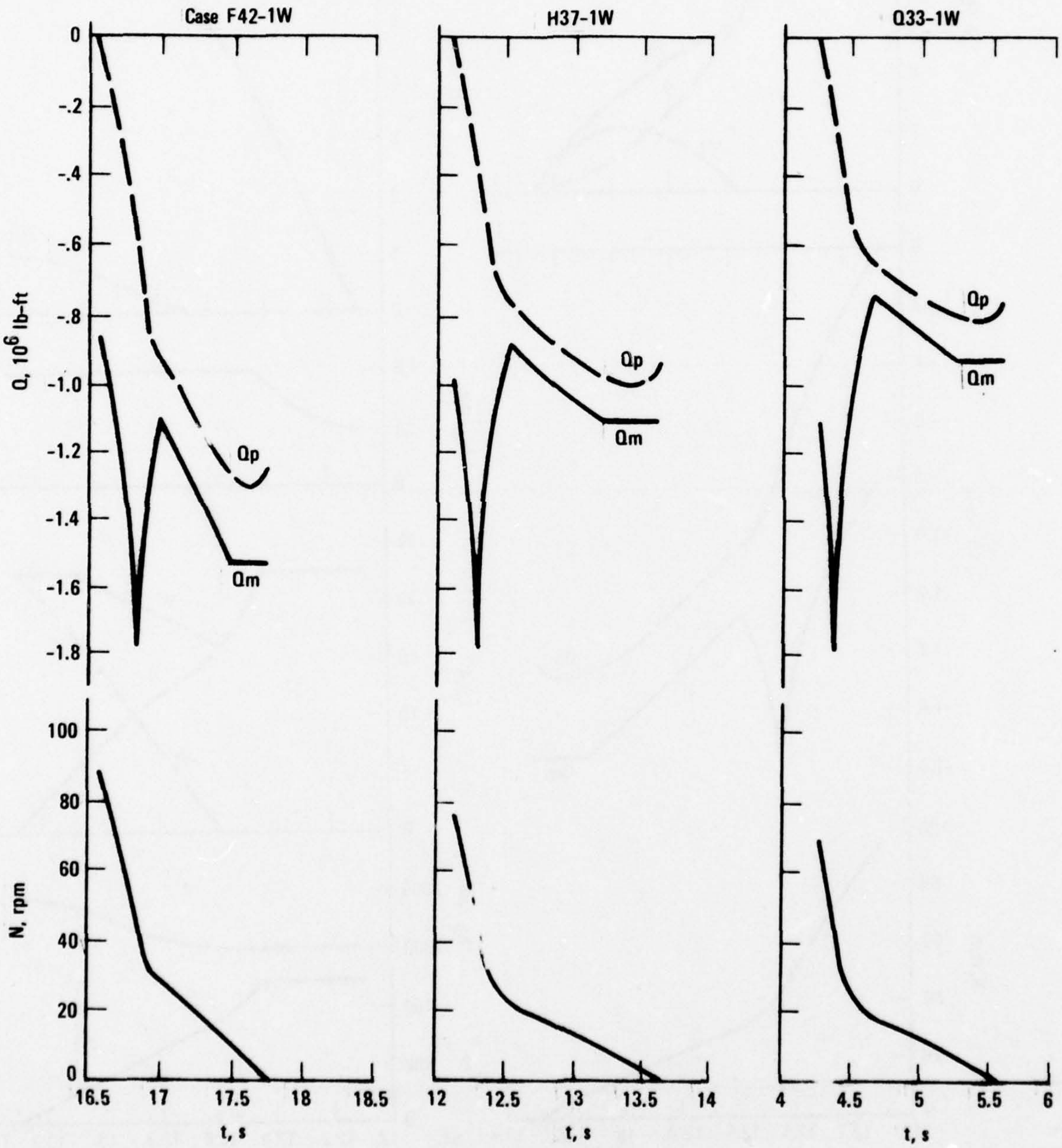


Figure 6-10 R = 0.0216 Ohm

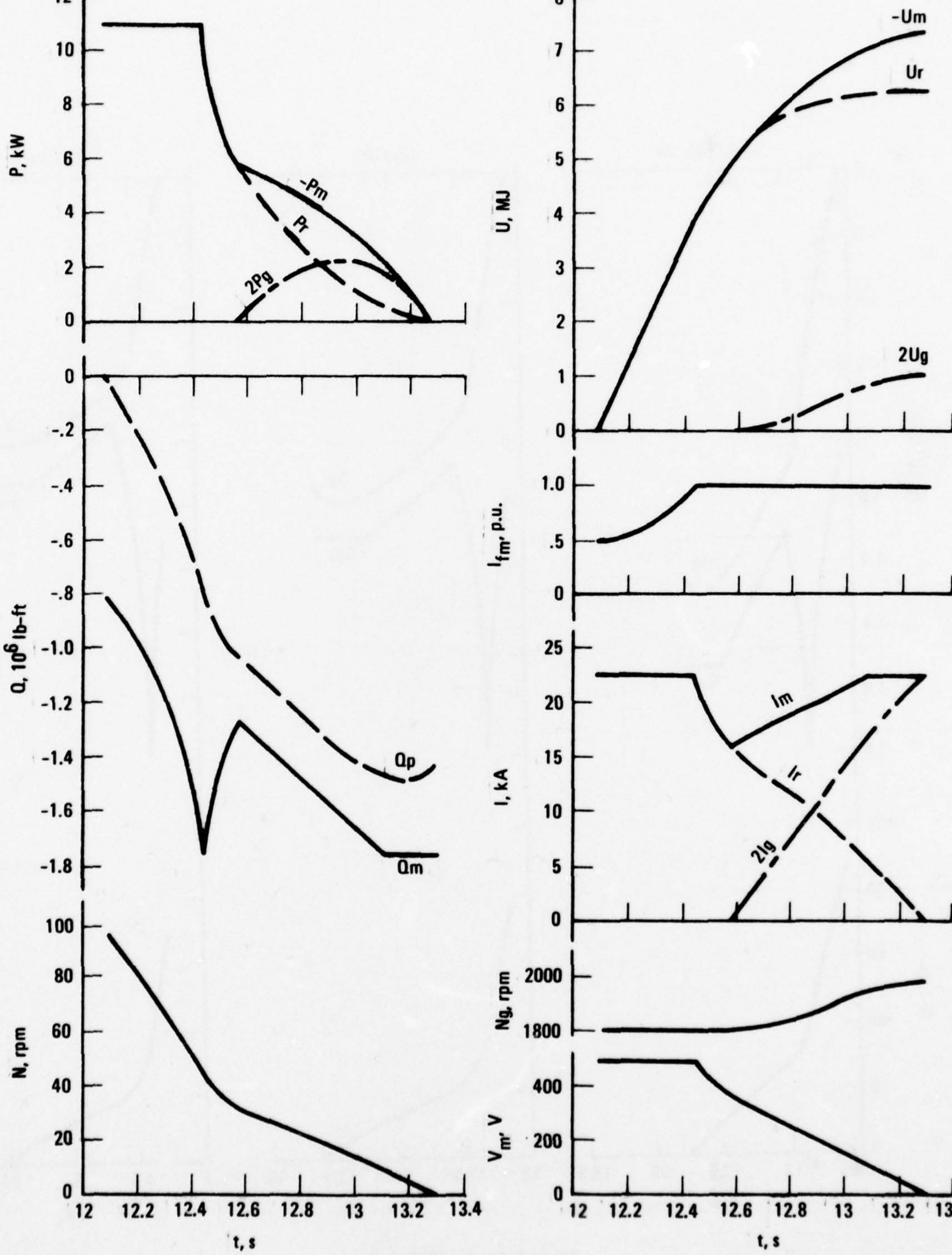


Figure 6-11 Reversal Process for Case F45-1W, R = 0.0216 Ohm

Table 6-3 Reversal Process Summary for Case F45-1W, R=0.0216 Ohm

Program Results								
t, s	12.100	12.250	12.453	12.585	12.750	12.950	13.109	13.299
N, rpm	93.98	73.21	43.86	31.79	24.75	16.42	9.35	0.0
Qm, 10^6 lb-ft	-0.820	-1.053	-1.757	-1.273	-1.425	-1.605	-1.756	-1.756
Qp, 10^6 lb-ft	0.008	-0.285	-0.778	-1.034	-1.185	-1.371	-1.461	-1.427
Pm, hp	-14,673	-14,673	-14,673	-7705	-6714	-5016	-3126	0
kW	-10,942	-10,942	-10,942	-5746	-5007	-3740	-2331	0
Um, MJ	0.0	-1.641	-3.867	-4.868	-5.760	-6.641	-7.133	-7.357
Δt, s	-	0.150	0.203	0.132	0.165	0.200	0.159	0.190
Δ Um, MJ	-	-1.641	-2.226	-1.001	-0.892	-0.881	-0.492	-0.224
Motor								
Ifm, p.u.	0.47	0.60	1.0	1.0	1.0	1.0	1.0	1.0
Vm, V	486	486	486.0	352.3	274.2	181.9	103.7	0
Im, A	22,500	22,500	22,500	16,308	18,254	20,559	22,500	22,500
Resistor								
I_r, A	22,500	22,500	22,500	16,308	12,697	8423	4800	0
P_r, kW	10,942	10,942	10,942	5746	3481	1532	498	0
ΔU_r, MJ	0	1.641	2.226	1.001	0.755	0.489	0.154	0.032
U_r, MJ	0	1.641	3.867	4.868	5.623	6.112	6.266	6.298
Per T-G Set								
Ig, A	0	0	0	0	2778	6068	8850	22,500
Pg, kW	0	0	0	0	763	1104	917	0
ΔUg, MJ	0	0	0	0	0.069	0.196	0.169	0.096
Ug, MJ	0	0	0	0	0.069	0.265	0.435	0.530
Ng, rpm	1800	1800	1800	1800	1824	1892	1949	1980

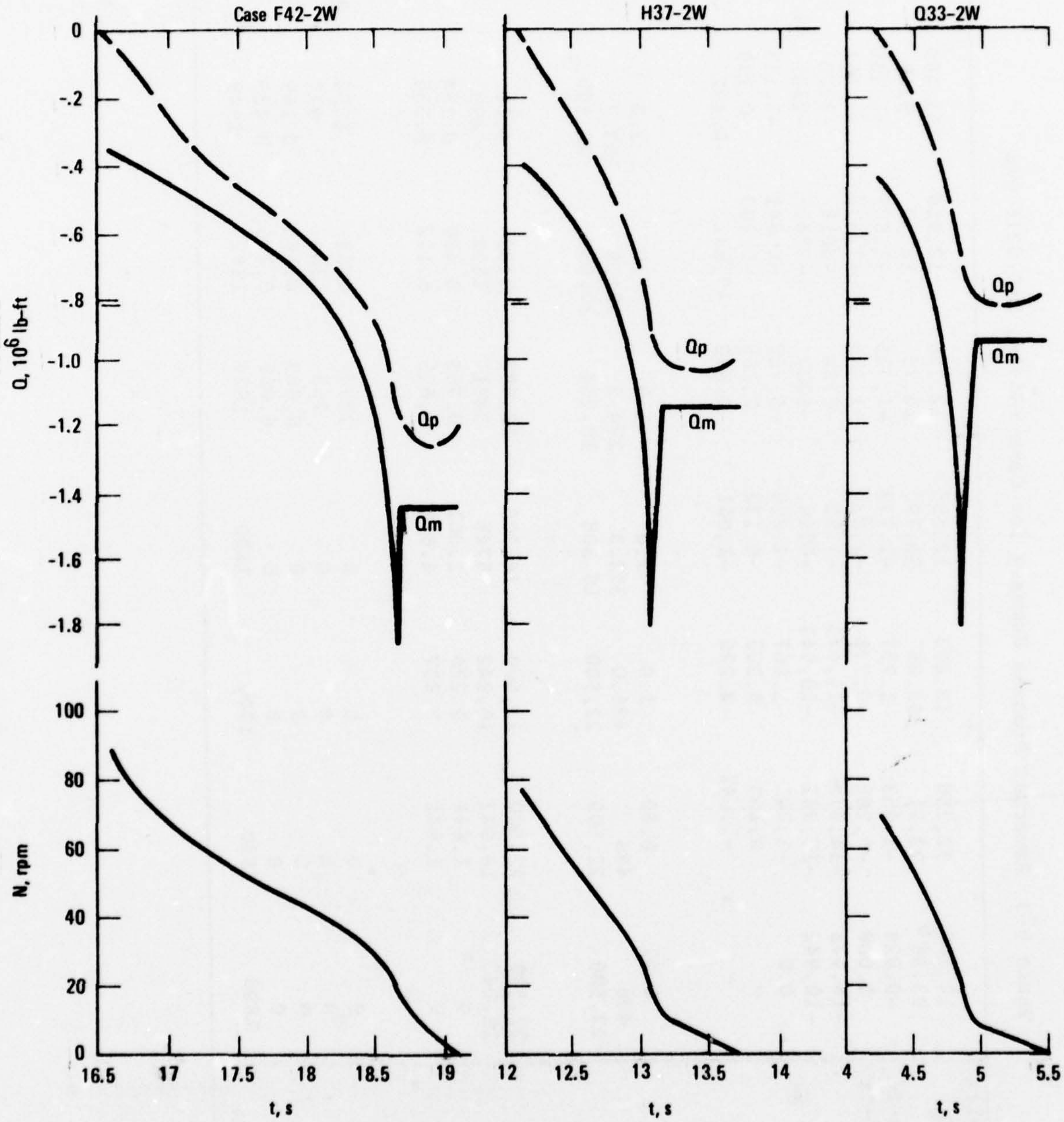


Figure 6-12 R = 0.0086 Ohm

Table 6-4 Saw Tooth Torque Crash Back Summary,
Reversal Process: Dynamic Resistor + Stored Energy [T-G Set Inertia(s)]

case	reversal									propeller reversed		total time to stop, s	head reach, ft
	R, ohm	Qm %		total energy, MJ	total time, s	peak power, hp	stored energy time, s	stored energy energy, MJ	stored energy N_{T-G} at end, rpm	N=0→ -8 rpm Qm, %	N=-8→ V=0 Qm, %		
F47-1S	0.0483	-150/-78	S/R	10.586	1.695	32,766	1.305	3.274	2311	-150	-120	44.5	1208
H37-1S		-118/-56		6.077	1.905	20,392	1.479	1.624	2308	-95	-76	55.8	1198
Q33-1S		-106/-46		4.563	1.864	16,403	1.382	1.160	2493	-79	-63*	55.0	864
F45-2S	0.0463	-150/-76	S/R	8.765	1.438	31,440	1.073	2.604	2216	-150	-120	46.2	1284
H37-2S		-123/-56		6.063	1.896	21,245	1.467	1.595	2299	-95	-76	55.8	1198
Q33-2S		-111/-47		4.510	1.832	17,103	1.356	1.116	2471	-79	-63*	55.0	864
F42-3S	0.0432	-150/-72	S/R	7.145	1.397	29,344	1.027	1.911	2113	-130	-120	49.3	1417
H37-3S		-132/-58		6.029	1.879	22,775	1.446	1.541	2284	-95	-76	55.8	1197
Q37-3S		-119/-48		4.508	1.829	18,317	1.342	1.088	2456	-79	-63*	54.9	863
F42-4S	0.0432	-150/-72	S/R	5.710	1.022	29,344	0.662	1.501	2050	-130	-120	49.2	1412
H37-4S		-132/-58		4.781	1.424	22,775	0.991	1.223	2193	-95	-76	55.7	1193
Q33-4S		-119/-48		3.577	1.312	18,317	0.825	0.753	2275	-79	-63*	54.8	860
F42-5S	0.0432/**	-150/-72	S/S/R	6.363	1.207	29,344	0.695	0.811	1939	-130	-120	49.2	1414
H37-5S		-150/-72		4.986	1.535	22,775	1.061	0.736	2046	-95	-76	55.6	1192
Q33-5S		-150/-64		3.543	1.351	18,317	0.907	0.467	2107	-79	-63*	54.8	858
F45-6S	0.0463/**	-150/-72	S/S/S/S/C	8.290	1.442	31,440	0.495	0.359	1863	-140	-120	46.2	1282
F40-7S	0.0412/**	-150/-65	S/S/S/S/C	5.619	1.193	27,946	0.233	0.097	1817	-120	-120	51.6	1511
F47-1W	0.0216	-150/-67	W/S/R	8.910	1.471	14,658	0.920	1.365	2029	-150	-120	44.5	1205
F45-1W		-150/-70		7.357	1.199	14,673	0.714	1.121	1990	-150	-120	46.1	1281
F42-1W		-150/-75		6.149	1.191	14,680	0.744	0.930	1959	-130	-120	49.2	1414
H37-1W		-150/-76		4.877	1.501	14,668	1.085	0.752	2051	-95	-76	55.6	1192
Q33-1W		-150/-63		3.508	1.324	14,675	0.928	0.483	2117	-79	-63*	54.8	858
F42-2W	0.0086	-150/-30	W/S/R	9.904	2.549	5,862	0.396	0.167	1829	-120	-120	49.9	1442
H37-2W		-150/-34		4.843	1.590	5,856	0.552	0.161	1857	-95	-76	55.8	1200
Q33-2W		-150/-38		3.133	1.202	5,846	0.493	0.099	1869	-79	-63*	54.9	861

**See notes for other resistor values.

* power limited (9361 hp)

Notes for Table 6-4

Table Heading	Description
case	Identifies each simulation run and indicates the power configuration and ship speed at the start of the reversal phase.

Initial Conditions

Power Configuration	Full	Half	Quarter
t, s	0	0	0
s, ft	0	0	0
V, ft/s	54.01	42.87	34.02
N, rpm	168.0	133.3	105.8
Q_m, %	100.0	63.0	39.7
P_m, hp	37,444	18,722	9,361

Start of Reversal

designation	F47	F45	F42	F40	H37	Q33
t, s	9.6	12.1	16.6	20.0	12.1	4.3
s, ft	486	603	798	937	488	144
V, ft/s	46.9	45.0	42.0	40.0	37.0	33.0
N, rpm	97.9	94.0	87.7	83.5	77.3	69.3

Notes for Table 6-4 (Continued)

Table Heading	Description
reversal R	Gives the dynamic resistor values per motor. The values given below for the two and four stage cases are the combined resistance of the stages connected in parallel.

Resistance Values, Ohm

Case	-5S	-6S	-7S
Stage 1	0.0432	0.0463	0.0412
Stage 2	0.0208	0.0222	0.0177
Stage 3	-	0.0148	0.0103
Stage 4	-	0.0108	0.0069

Q_m — Gives the maximum and minimum motor torques during the reversal phase. An indication of the motor torque characteristics during the reversal phase is given by the following four letters:

S, (saw tooth) $Q_m \propto N$
Simulates a dynamic resistor stage with full motor field.

R, (ramp) $Q_m = CONST_1 + CONST_2 \times N$
Simulates a dynamic resistor plus stored energy (Note: near N=O, Q_m=CONST)

C, (constant) Q_m=CONST
Simulates a dynamic resistor plus stored energy with constant motor current

W, (weakened motor field) $Q_m \propto 1/N$
Simulates a dynamic resistor with constant motor current.

Notes for Table 6-4 (Continued)

Table Heading	Description
total energy	Gives the sum of the energy dissipated (resistor) and energy stored (inertia) during the reversal process per motor.
time	Gives the duration of the reversal phase.
peak power	Gives the peak power generated per motor during the reversal phase.
stored energy time	Gives the time interval during which energy is being both dissipated and stored.
energy	Gives the energy stored per motor.
N_{T-G}	Gives the turbine-generator set rotational speed(s) at the end of reversal assuming an initial speed of 1800 rpm.
propeller reversed N=0→ -8 rpm Qm	Gives the (constant) motor torque from the time the propeller is stalled until the time the propeller speed is -8 rpm.
N=-8→ V=0 Qm	Gives the (constant) motor torque from the time at which the propeller speed is -8 rpm until the time at which the ship is dead in the water.
total time to stop	Gives the total time from the start of the maneuver until the ship is dead in the water.
head reach	Gives the total distance traveled.

7

APPENDIX NO. 7

3000 HORSEPOWER PER SHAFT DRIVE, SYSTEM CONTROLS

1. INTRODUCTION

Major emphasis is placed upon the central part of the control system, the master control unit which comprises the dynamic control section, lower level supervisory control section, and upper level supervisory control section.

In part 2. the general organization of the control system is presented and the function of each of the three sections of the master control unit is given. A detailed description of these sections is given in parts 3., 4., and 5.

2. OVERVIEW

2.1 Organization

The general organization of the control system is illustrated by the block diagram in Figure 1. The master control unit which is the central part of the control system is divided into three sections as indicated by the three control blocks.

The inputs to the master control unit consist of operator commands from the control console, parameters sensed in the drive system (e.g. currents, voltages, etc.), and feedback information from other control units.

The master control unit generates inputs to the test stand controls, switch and circuit breaker controls, exciter controls, and dynamic resistor controls.

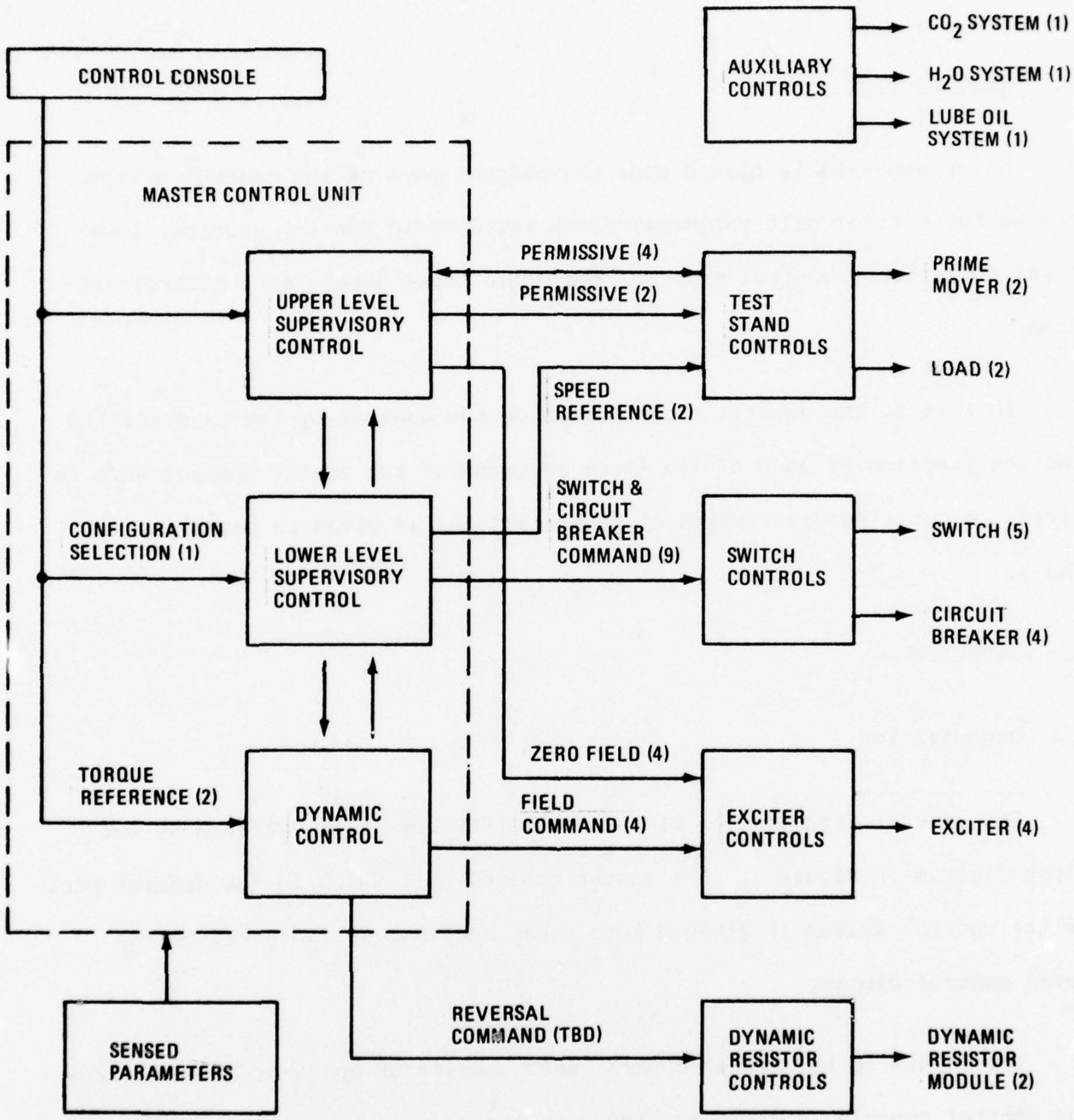


Figure 1 Master Control Unit Block Diagram

The auxiliary controls for the CO_2 system, H_2O system, and lube oil system are regulated at the local level. Although the master control unit does not command these systems, it assesses the status of each via selected sensed parameters (e.g. lube oil pressure).

The start up and shut down of the prime movers are under test stand control, however, there is a permissive interlock between the prime mover controls and the master control unit. Also, the prime mover controls strive to match the speed of each prime mover with its respective reference speed which is input from the master control unit.

The switch controls open and close the switches and circuit breakers in the SEGMAG power circuit in response to the five switch commands and four circuit breaker commands generated by the master control unit.

The exciters, including their controls, are energized locally. Each exciter provides a source of variable dc voltage for a single machine field. In response to the field commands from the master control unit, the exciter controls vary the voltage output from each exciter and thus the field currents. In addition, the field currents may be rapidly forced to zero by giving a second set of commands (i.e. zero field) from the master control unit.

The dynamic resistor controls activate the dynamic resistor modules in response to commands from the master control unit. These commands are only given during a reversal (i.e. crash back) simulation.

2.2 Functions

The control functions performed by each of the three sections of the master control unit are highlighted in Figure 2 and expanded upon in the paragraphs to follow. The functions for each section are split into two categories, conditional and continuous. The conditional category is further divided into active mode and passive mode.

The function of the dynamic control section is to control the drive system in response to the side 1 and side 2 torque references. This is accomplished through the field commands to the exciter controls and the reversal commands to the dynamic resistor controls. The manner in which the exciters and dynamic resistor modules are controlled depends upon the power configuration.

The field commands are continuously controlled as functions of the power configuration, reference torques, and electromagnetic torques developed by the motors. Part or all of these commands are overridden whenever any one of the three control sections is in the active mode.

In the passive mode, the dynamic control determines if a reversal is required. Whenever this condition arises, the active mode is initiated and a reversal is achieved by executing a fixed program.

The lower level supervisory control performs the functions of configuration control and generation of speed references for the prime movers. In the passive mode, the operator selected configuration is compared with the configuration in which the drive system is operating. If they differ, the active

CONTROL SECTION	CONTROL FUNCTION		
	CONDITIONAL		CONTINUOUS
	MODE/RESPONSE	ACTIVE MODE CONDITION(S)	
UPPER LEVEL SUPERVISOR	Active/Take over lower level supervisor and dynamic control functions Passive/Detect occurrence of conditions	• Start up • Shut down • Restart • Emergency • Fault	• Permissives
LOWER LEVEL SUPERVISOR	Active/Take over all field commands Switch position commands Passive/Detect if a transition is required Switch position commands static	• Transition	• Speed Reference
DYNAMIC	Active/Reversal commands Take over generator field commands Passive/Detect if a reversal is required Reversal commands static	• Reversal	• Generator and motor field commands (unless overridden)

Figure 2 Master Control Unit Functions

mode is initiated and a transition is performed which establishes a new configuration by changing switch and circuit breaker positions.

The most important functions of the upper level supervisor are of the conditional type. In the passive mode, the system is monitored for the occurrence of five categories of conditions which are anticipated to arise infrequently. When one of these conditions occurs, the upper level supervisor takes over control of the drive system (active mode). A brief description of each condition follows:

START

Each time the control system is energized, a start up sequence is carried out which readies the system for operation.

STOP

Before deenergizing the control system, the stop sequence is carried out which provides for an orderly shut down of the drive system.

RESTART

Upon detecting a system malfunction, a restart sequence is carried out which places the control system and drive system in the states they would be in at the end of a start up sequence.

EMERGENCY

Emergency conditions are any occurrences which require immediate and rapid shut down of the drive system with the exception of electrical faults in the SEGMAG armature circuit(s).

FAULT

Upon detecting a fault, the circuit breakers are opened, the machine fields are immediately forced towards zero, and the drive system is rapidly shut down.

In addition to the conditional control functions given above, the upper level supervisor also provides a permissive interlock with the test stand controls. For instance, in order for the prime movers to be allowed to run certain conditions must be met, e.g. the lube oil systems must be operating.

2.3 Sensed Parameters

Although numerous sensors are located throughout the drive system, only those sensed parameters which are input to the master control unit are discussed here. Figure 3 shows the major components of the drive system and indicates the location of the sensors exclusive of those in the CO_2 system, H_2O system, and lube oil system.

Each SEGMAG generator (GT1 and GT2) is driven directly by a prime mover (PM1 and PM2). Each SEGMAG motor (M1 and M2) is directly coupled to a load device. Each SEGMAG machine is separately excited (EX G1 ... EX M2). Located in the electrical power circuit are five switches (S1 through S5), four circuit breakers (CB1 through CB4), and two dynamic resistor modules (DRM1 and DRM2).

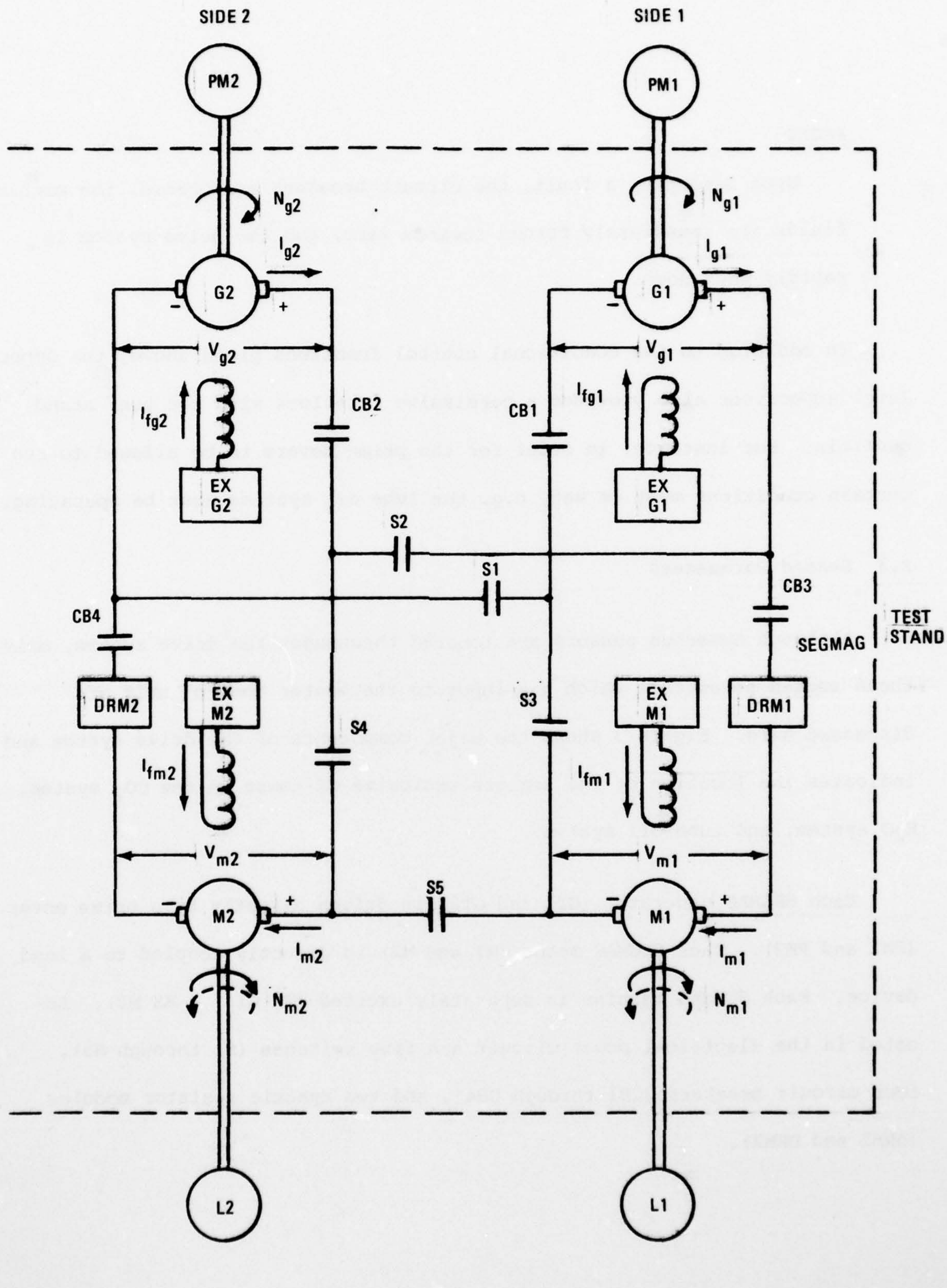


Figure 3 Drive System Sensors

The sensed parameters indicated in Figure 3.6-3 are listed below:

$N_{g1} \ldots N_{g2}$,	Generator-prime mover rotational speed
$V_{g1} \ldots V_{g2}$,	Generator voltage
$I_{g1} \ldots I_{g2}$,	Generator current
$I_{fg1} \ldots I_{fg2}$,	Generator field current
N_{m1}, N_{m2},	Motor-propeller rotational speed
V_{m1}, V_{m2},	Motor voltage
I_{m1}, I_{m2},	Motor current
I_{fm1}, I_{fm2},	Motor field current
S1...S5,	Switch position
CB1...CB4,	Circuit breaker position

The switch and circuit breaker position parameters are of type logical, being true (logical 1) when the switch is closed and false (logical 0) when the switch is open.

At each SEGMAG machine, critical parameters are sensed which pertain to the CO_2, H_2O, and lube oil systems. The make up of these parameters is to be determined. The purpose of these parameters is to ascertain the status of the three systems and thereby establish whether or not a SEGMAG machine may be included in the drive system.

2.4 Configurations

There are four basic configurations: zero, quarter, half and full power. Most of these have several versions which brings the total number of power configurations to eight.

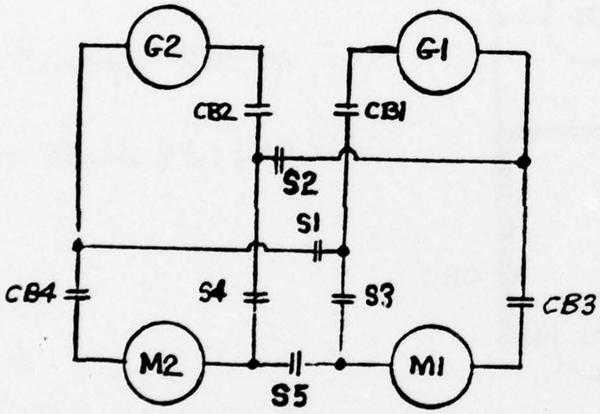
Figure 4 shows the armature connection diagram for the zero power configuration, Z. All circuit breakers (CB1 thru CB4) and switches (S1 through S5) are open.

The two quarter power configurations, Q1 and Q2, are shown in Figure 5. In these configurations, one generator and the two motors are connected in series.

Three half power configurations are available, H, H1, and H2 as shown in Figure 6. In these configurations, the drive system is operating in the split plant mode, i.e. side 1 and side 2 are electrically isolated from one another.

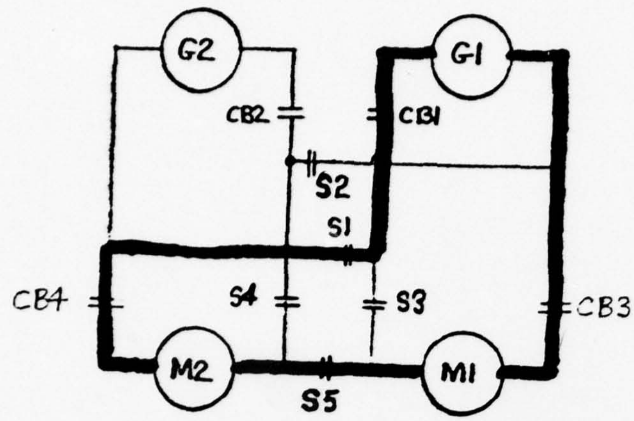
Figure 7 shows the two full power configurations, F1 and F2. Two generators in parallel power one motor.

The allowable transitions between the eight configurations are shown pictorially in Figure 8. At the top of the figure is a matrix showing the generators and motors operating for the various configurations.



all switches (S1 thru S5)
and circuit breakers
(CB1 thru CB4) open

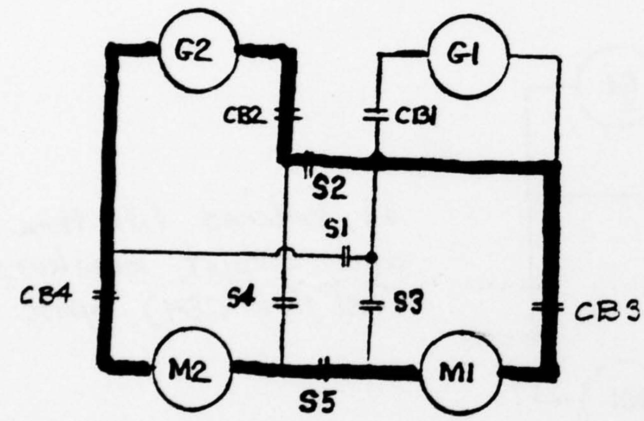
Figure 4 Armature Connection Diagram,
Zero Power Configuration (Z)



a) Q1

G1, M1, M2 operating

CB1, CB3, CB4, S1, S5 closed

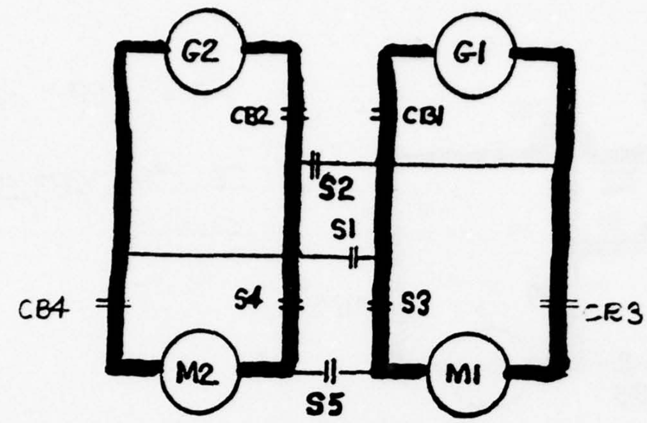


b) Q2

G2, M1, M2 operating

CB2, CB3, CB4, S2, S5 closed

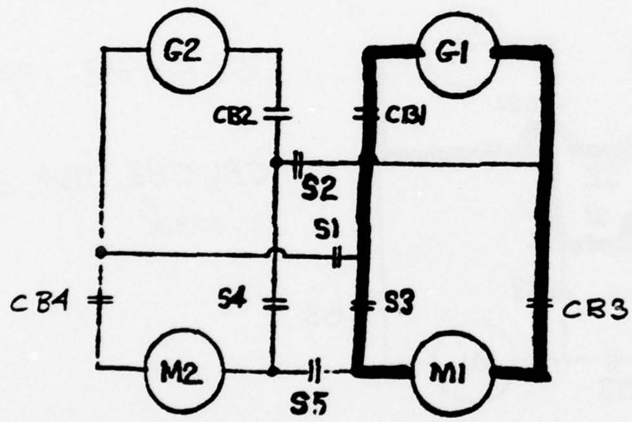
Figure 5 Armature Connection Diagram,
Quarter Power Configurations



G1, G2, M1, M2 operating

CB1, CB2, CB3, CB4, S3, S4 closed

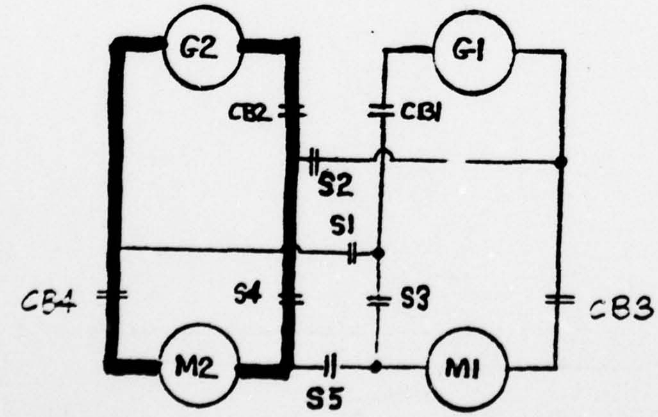
a) H



G1, M1 operating

CB1, CB3, S3 closed

b) H1

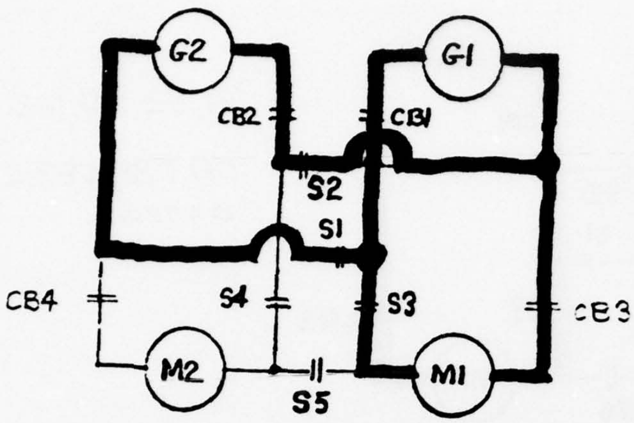


G2, M2 operating

CB2, CB4, S4 closed

c) H2

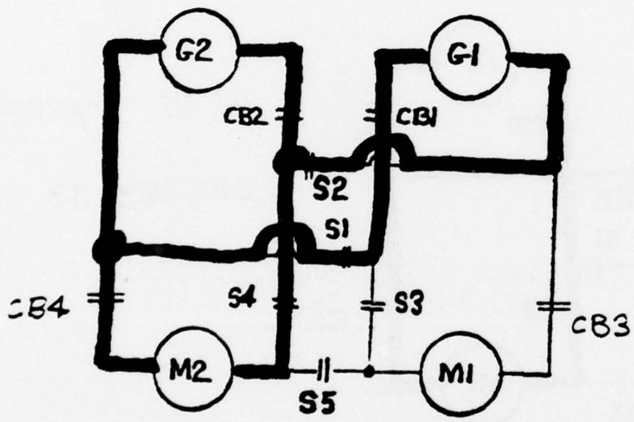
Figure 6 Armature Connection Diagram, Half Power Configurations



G1, G2, M1 operating

CB1, CB2, CB3, S1, S2, S3 closed

a) F1



G1, G2, M2 operating

CB1, CB2, CB4, S1, S2, S4 closed

b) F2

Figure 7 Armature Connection Diagram, Full Power Configurations

Configuration Table

		generators operating			
		none	1	2	1&2
motors operating	none	Z	—	—	—
	1	—	H1	—	F1
	2	—	—	H2	F2
	1&2	—	Q1	Q2	H

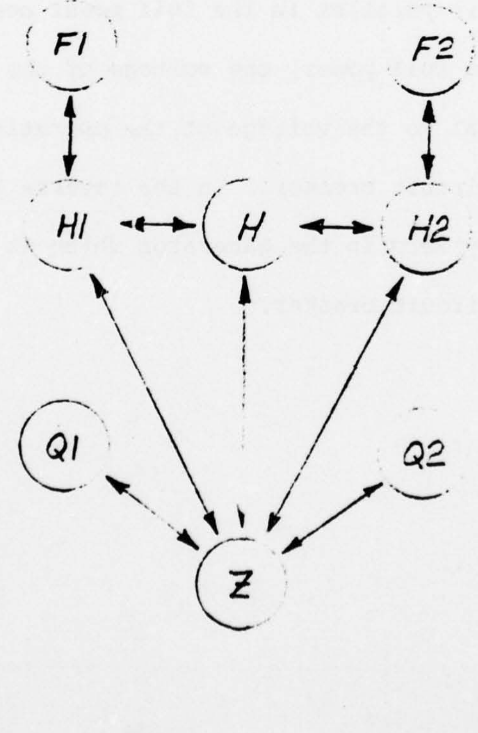


Figure 8 Allowable Transitions Between Configurations

In transitioning from the quarter and half power configurations to the zero power configuration, the current must be approximately zero before opening the armature circuit. In carrying out the reverse transitions, the sum of the voltages around the circuit(s) must be approximately zero before closing the circuit breaker(s). The zero power configuration serves as an intermediary between the quarter and the half power configurations, i.e. the system must first be deenergized before configuring from the quarter to half power configuration or vice versa.

The transitions between the half and full power configurations, H1-F1 and H2-F2, can be performed without deenergizing the system because the generators are connected in parallel in the full power configuration. When transitioning from half to full power, the voltage of the available generator must be approximately equal to the voltage of the operating generator before closing the appropriate circuit breaker. In the reverse transition, the current must be approximately zero in the generator which is to be taken off the line before opening its circuit breaker.

2.5 Supplementary Information

The detailed description of each control section in parts 3., 4., and 5. makes extensive use of block diagrams. An explanation of the block diagram symbols is given in Figure 9.

Also, when numerical values are given, they will usually be on a p.u. (per unit) basis. The base values and ranges of pertinent parameters are listed in Table 1. For any given parameter, the physical value is the product of the per unit value and base value. For instance, if the motor speed is 0.5 p.u., the physical rotational speed is then 0.5 x 1200 rev/min = 600 rev/min.

Table 1. Parameter Base Values and Ranges

Parameter	Base Value	Nominal Range, p.u.
Generator:		
Voltage	500 V	-1.0 to +1.0
Current	4474.2 A	-1.0 to +1.0
Field Current	172.2 A	-1.12 to +1.12
Power	2237.1 kW	0 to +1.0
Speed	600 rev/min	0 to +1.0
Motor:		
Voltage	500 V	-1.0 to +1.0
Current	4474.2 A	-1.0 to +1.0
Field Current	173 A	0 to +1.0
Power	2237.1 kW	0 to +1.0
Speed	1200 rev/min	-1.0 to +1.0
Torque	17.8 kNm	-1.0 to +1.0

Note: During reversal the generator currents, motor currents, and motor torques may exceed the limits shown by approximately 50 percent. In addition, the motor power becomes temporarily negative.

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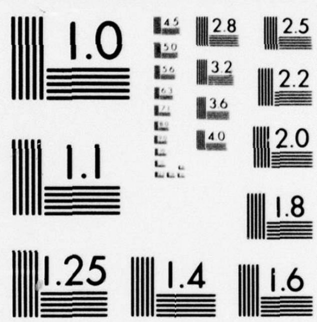


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

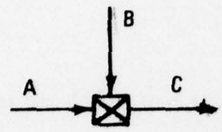
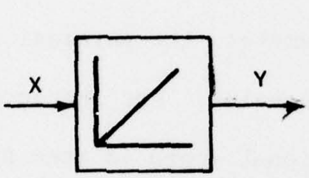
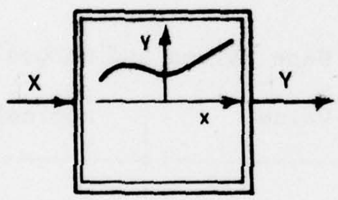
NAME	SYMBOL	DESCRIPTION
MULTIPLER		$C = A \times B$
INTEGRATOR		$y = \int x\,dt$
FUNCTION		$y = f(x)$

Figure 9a Block Diagram Symbols

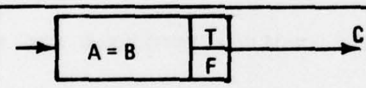
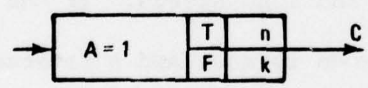
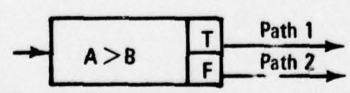
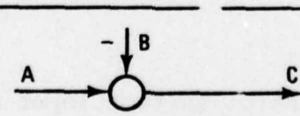
NAME	SYMBOL	DESCRIPTION
LOGICAL RELATIONAL OPERATORS	$=$ $\neq$ $<$ $\leqslant$ $>$ $\geqslant$	Equal to Not equal to Less than Less than or equal to Greater Greater than or equal to
LOGICAL OPERATORS	.AND. .OR.	And Or
LOGICAL EXPRESSION (VALUE)	 	C is true (logical 1) if A = B C is false (logical 0) if A $\neq$ B C = n if A = 1 C = k if A $\neq$ 1 Note: If A is a logical parameter then C = n if A is true (logical 1). If A is false (logical 0) then C = k.
(BRANCH)		Path 1 is followed if A > B Path 2 is followed if A $\leqslant$ B
SUMMER		C = A – B

Figure 9b Block Diagram Symbols

3. DYNAMIC CONTROL

3.1 Functions

The function of the dynamic control is to control the machine fields and dynamic resistor modules in response to the torque references.

Four field commands are continuously generated as functions of the reference torques, motor torques, and power configuration. Unless overridden, each command provides the error signal input to one of the four exciters. The field characteristics under steady state operating conditions are shown in section ________ as functions of motor speed and power configuration.

In the passive mode, the dynamic control monitors the sign (i.e. plus or minus) of the torque references and load speeds. If the signs are not identical, a change to the active mode is made and a reversal is achieved by executing a fixed program. This program regulates the generator and motor field commands and sequences the reversal commands to the dynamic resistor modules in a predetermined manner.

3.2 Input/Output

Figure 10 shows the dynamic control section input and output. Also shown is a simplified block diagram which is described in the next section.

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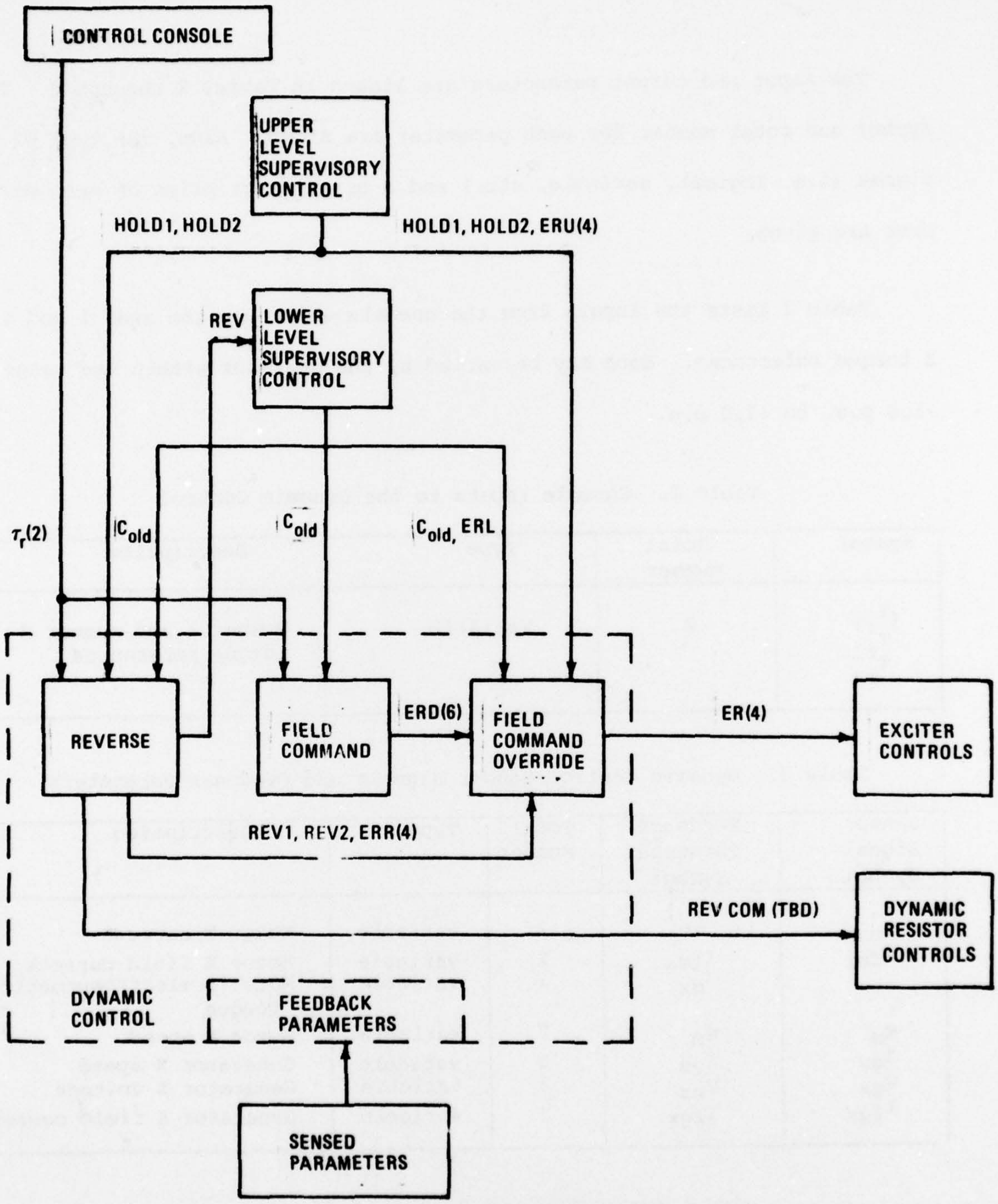


Figure 10 Dynamic Control Input/Output and Block Diagram

The input and output parameters are listed in Tables 2 through 8. The symbol and total number for each parameter are shown. Also, the type of signal (i.e. logical, variable, etc.) and a brief description of each parameter are given.

Table 2 lists the inputs from the console which are the side 1 and side 2 torque references. Each may be varied by the operator within the range of -1.0 p.u. to +1.0 p.u.

Table 2. Console Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
(τ_r) τ_{r1} τ_{r2}	2	Variable	Number 1 and number 2 torque references

Table 3. Dynamic Control Sensor Signals and Feedback Parameters

Sensor Signal Symbol	Feedback Parameter Symbol	Total Number	Type	Description
I_{mx}	--	2	variable	Motor X current
I_{fmx}	I_{fmx}	2	variable	Motor X field current
--	τ_{mx}	2	variable	Motor X electromagnetic torque
N_m	N_m	2	variable	Motor X speed
I_{gx}	I_{gx}	2	variable	Generator X speed
V_{gx}	V_{gx}	2	variable	Generator X voltage
I_{fgx}	I_{fgx}	2	variable	Generator X field current

Note: "X" in the symbols has the values 1 thru "total number."

Table 4. Lower Level Supervisor Control Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
C_{old}	1	discrete variable	Gives the configuration in which the drive system is operating: Z, Q1, Q2, H1, H, H2, F1, or F2. During transition, C_{old} has the value NC.
(ERL) ERL_{g1} ERL_{g2} ERL_{m1} ERL_{m2}	4	variable	Field commands-only used during transition.

Table 5. Upper Level Supervisor Control Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
HOLD1	1	logical	Upper level is in the passive mode (logical 0) or active mode (logical 1) with respect to side 1.
HOLD2	1	logical	Upper level is in the passive or active mode with respect to side 2.
(ERU) ERU_{g1} ERU_{g2} ERU_{m1} ERU_{m2}	4	variable	Field commands-only used when upper level is in the active mode.

Table 6. Dynamic Control Inputs to the Lower Level Supervisory Control

Symbol	Total Number	Type	Description
REV	1	logical	During reversal, the dynamic control is in the active mode (logical 1).

Table 7. Dynamic Control Inputs to the Exciter Controls

Symbol	Total Number	Type	Description
(ER) ER_{g1} ER_{g2} ER_{m1} ER_{m2}	4	variable	Field command error signals, one per exciter.

Table 8. Dynamic Control Inputs to the Dynamic Resistor Controls

Symbol	Total Number	Type	Description
REV COM	TBD	logical	Activates the dynamic resistors.

Table 3 lists the 14 sensor signals required by the dynamic control. Of these, all but the motor current signals, I_{m1} and I_{m2}, are used directly as feedback parameters.

The value of the motor current, I_m, is multiplied by the motor field current, I_{fm}, in order to obtain the feedback parameter τ_m which is the motor electromagnetic torque. The above formulation is on a per unit basis and applies to both motors.

Table 4 lists the inputs from the lower level supervisor. When the lower level is in the passive mode, the discrete variable C_{old} identifies which of the eight configurations the propulsion system is operating in. In the active mode, i.e. during transition, it is given the value "NC."

The four field commands are only used as input to the exciter controls during transition.

Table 5 lists the inputs from the upper level supervisory control. The logical parameters HOLD1 and HOLD2 which apply to side 1 and side 2 respectively indicate if the upper level is in the passive or active mode.

The four field commands are only used as input to the exciter controls when the upper level is in the active mode.

Table 6 shows the logical parameter REV which is input to the lower level supervisory control. During a reversal, REV has the value of 1 with the result that the lower level is inhibited from making a configuration change.

Table 7 lists the exciter control inputs from the dynamic control. There is one error signal for each of the four machine exciters. A positive error signal results in increasing the field current in the positive direction. With a zero input, the field current is held constant. A negative error signal reduces the value of the field current.

Table 8 shows the dynamic resistor module inputs from the dynamic control. The number of signals is not yet established.

3.3 Block Diagram

Following a brief discussion of the roll played by each of the three blocks in the dynamic control section (Figure 10), a description of the internal functioning of each is given.

The FIELD COMMAND block strives to match the motor torques with the reference torques through four field command error signals (ERD). These continuously generated error signals pass through the FIELD COMMAND OVERRIDE block unaltered and are input to the exciter controls (ER) as long as all three control sections are in the passive mode. In the active mode, part or all of the FIELD COMMAND error signals are replaced by error signals from the REVERSE block (ERR), the lower level supervisor (ERL), or the upper level supervisor (ERU).

The modes of the three control sections are indicated by the values of C_{old}, HOLD1, HOLD2, REV1, and REV2.

The REVERSE block contains the logic for detecting the need for a reversal and the programs for carrying out same.

3.3.1 FIELD COMMAND Block

The FIELD COMMAND block generates error signals for each machine exciter in response to the reference torques. The manner in which these error signals are determined depends upon the power configuration, there being four basic configurations: full power, half power, quarter power, and zero power. In the following, a (typical) arrangement for each configuration is described.

Figure 11 shows the field command diagram for the full power configuration, F1. The error signal for generator exciter 1, ERD_{g1}, is equal to the torque error on side one, i.e. the reference torque τ_{r1} minus the motor torque τ_{m1}. Thus the field of generator 1 responds directly to the torque error.

If the reference torque is greater than the motor torque, the error signal ERD_{g1} is positive which causes the field of generator 1 to increase. When the motor torque matches the reference torque, the error signal to generator exciter 1 is zero and the field is held at a constant value. If the torque error is negative, the field of generator 1 decreases in value.

The error signal for generator exciter 2, ERD_2, is the difference between the armature currents of generators 1 and 2. The error signal is zero only when the two currents balance each other. These two generators operate in parallel and thus when their currents are equal, they share the load evenly.

In the full power configuration, the field of the motor which is operating in the system is held constant at its upper limit of 1 p.u. (173 A). As shown in the diagram, the motor exciter 1 error signal is zero only if the motor field current, I_{fm1}, is 1 p.u. The field current of the motor which is not operating in the system, I_{fm2}, is commanded to be zero.

Figure 12 shows a typical field command diagram for the half power configuration, H1. Here generator 1 is driving motor 1 while side 2 is shut down. Two other combinations are of course possible, both sides operating (H), and side 1 shut down and side 2 operating (H2).

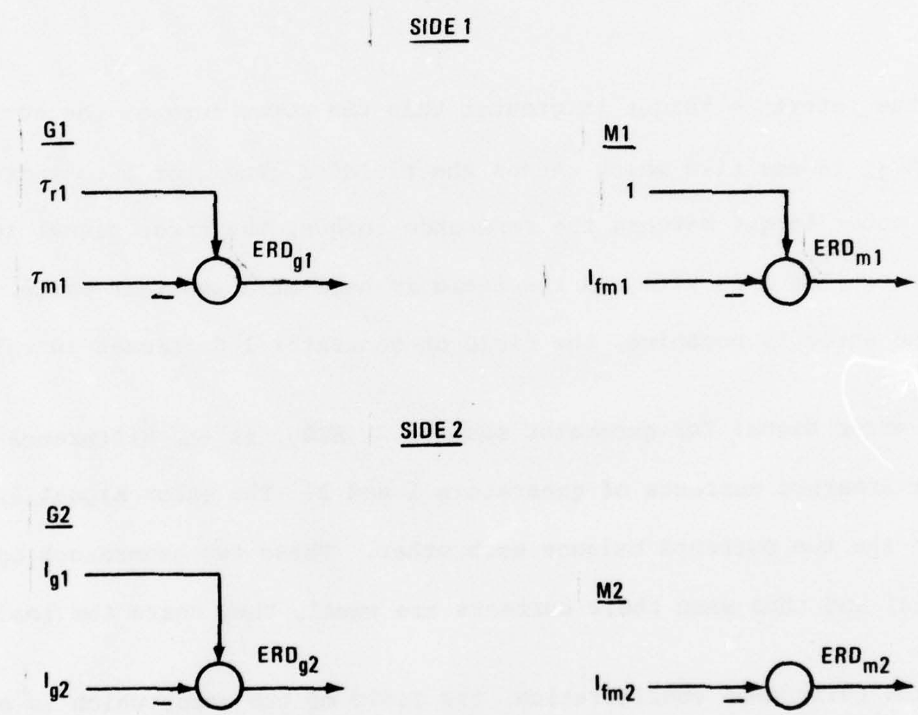


Figure 11 Field Command Diagram Full Power Configuration – F1

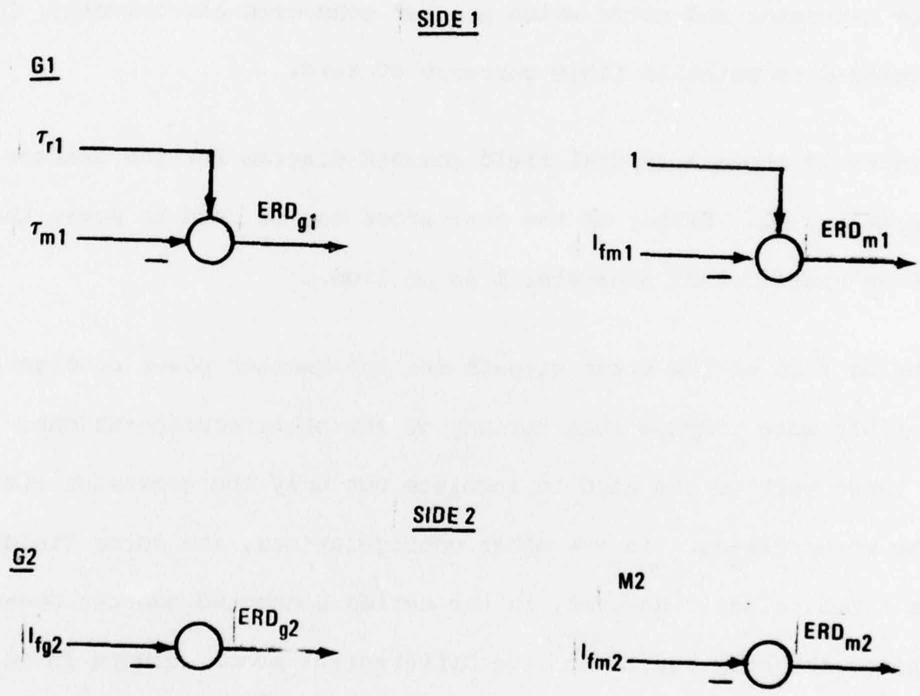


Figure 12 Field Command Diagram, Half Power Configuration – H1

The make up of the error signals for the half power configuration is very similar to that used for the full power configuration. The motor field, I_{fm1}, is again held at its upper limits (173 A). The torque error, $\tau_{r1}-\tau_{m1}$, is used as the error signal for the generator G1 which is powering the motor M1. The generator and motor which are not connected electrically, G2 and M2, are commanded to maintain field currents of zero.

Figure 13 shows a typical field command diagram for the quarter power configuration, Q1. Either of the generators may be used to power the motors. Here it is assumed that generator 1 is on line.

The make up of the error signals for the quarter power configuration is considerably more complex than for any of the other configurations. This is due in large part to the need to regulate not only the generator field but also the motor fields. In the other configurations, the motor fields are held at fixed values. However, in the series connected quarter power configuration, the only way to achieve differential motor torques is to adjust the motor fields individually in response to the applicable torque reference.

Referring to Figure 13, the torque error, τ error, is set equal to the torque error on the side with the largest reference torque absolute value. This error signal is input to an integrator with an output limited to the range of -1.0 to +1.0.

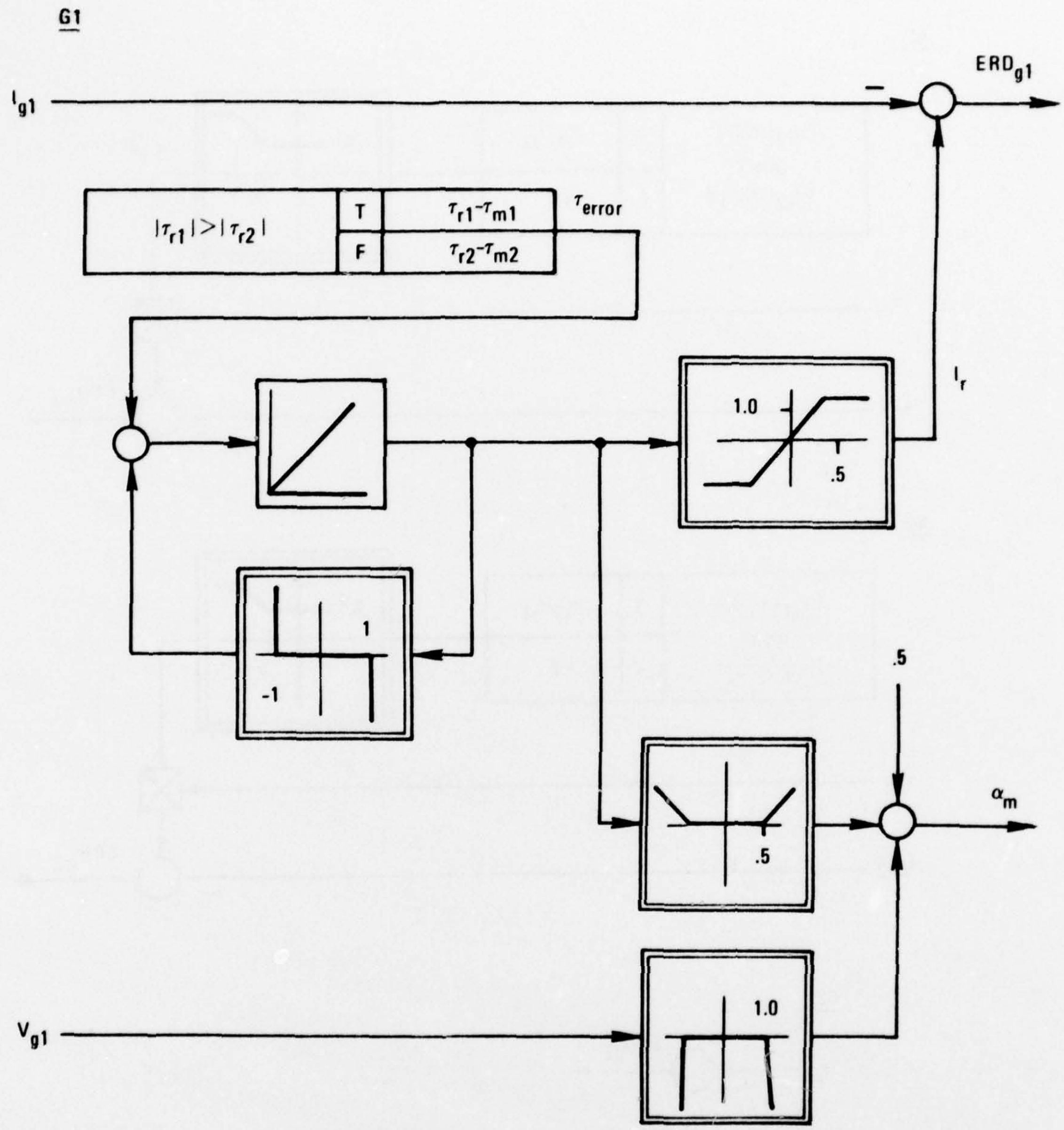


Figure 13a Field Command Diagram, Quarter Power Configuration – Q1

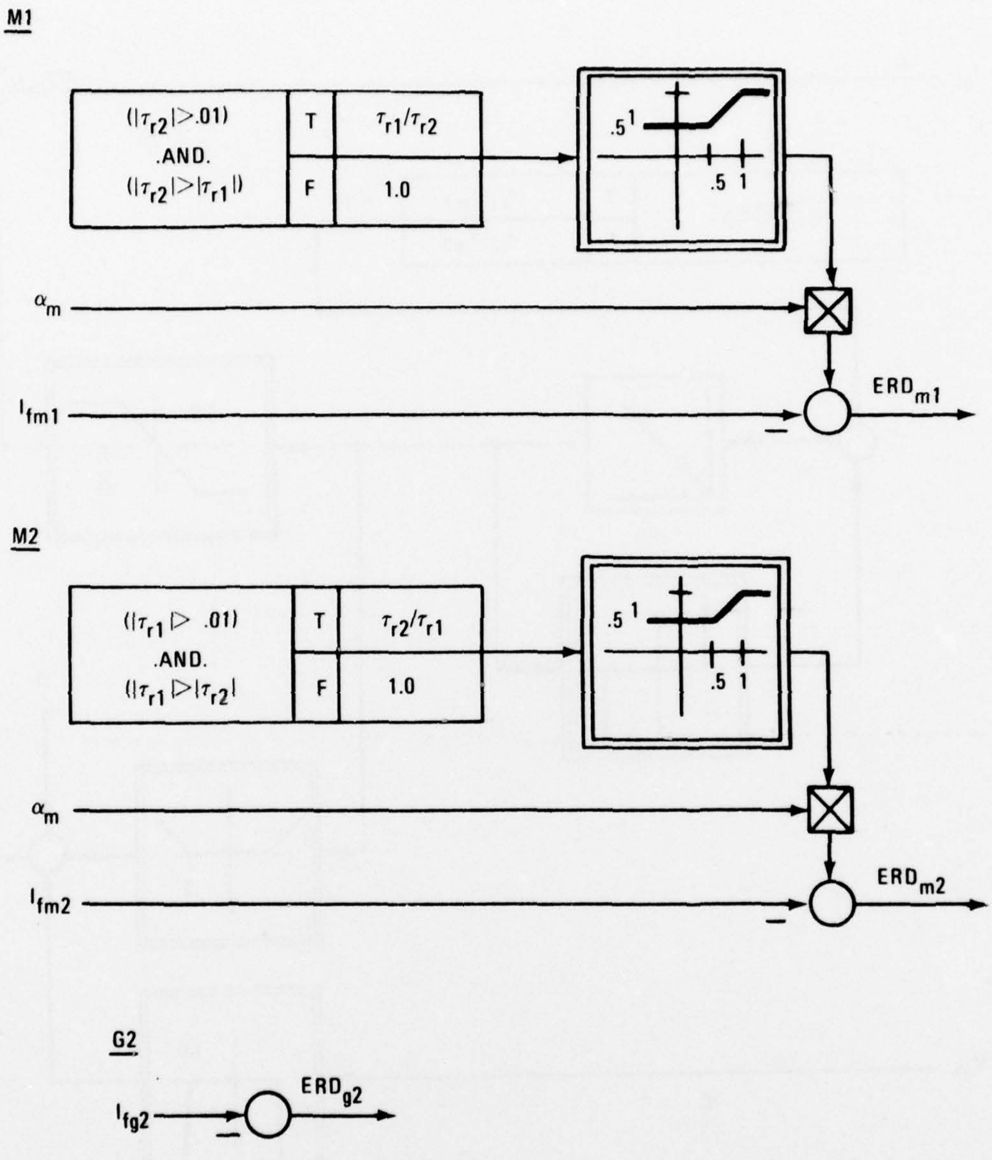


Figure 13b Field Command Diagram, Quarter Power Configuration - Q1

The integrator output serves two functions. The first is to set the value of the reference current, I_r, which is used to adjust the generator field. The second is to vary the parameter α_m which is used to control the motor fields.

When the integrator output is within the range of -0.5 to +0.5, the reference current is proportional to the output and the parameter α_m has a constant value of 0.5. Outside this range, the reference current is limited to a value of plus or minus 1.0 ($\pm$4474A). The parameter α_m increases to a limiting value of 1.0 unless the generator voltage exceeds 1.0 (500V). At the quarter power operating point under balanced steady state conditions, α_m would be 0.630 and the motor fields would have values of 0.630 p.u.

The motor exciter error signals, ERD_1 and ERD_2, are shown in Figure 13b. Under balanced conditions, i.e., equal reference torques, the motor fields are adjusted to equal α_m on a per unit basis. Under unbalanced conditions, the motor fields may be varied up to a ratio of 2 to 1. At very small reference torque values (-0.01 to +0.01) differential torque control is inhibited.

Figure 14 shows the field command diagram for the zero power configuration. The error signals to all generators are zero and thus the generator fields are not changed from the values they have after transition to this configuration. The motor fields are held constant at their upper limits.

This configuration serves as an intermediary between the quarter power and half power configurations wherein all of the switches and circuit breakers are open.

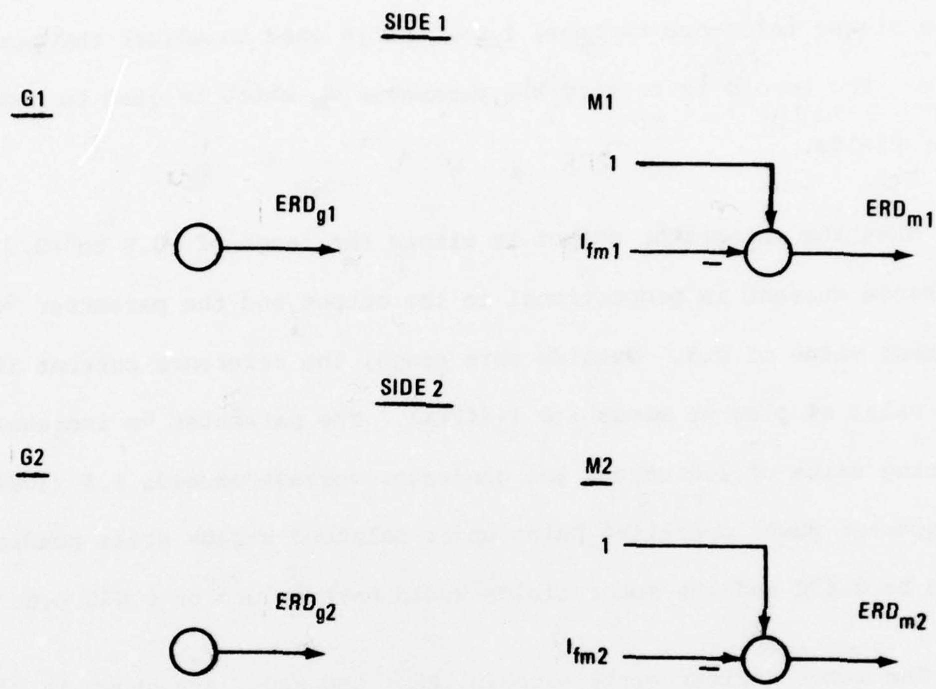


Figure 14 Field Command Diagram, Zero Power Configuration – Z

3.3.2 FIELD COMMAND OVERRIDE Block

Basically the field command override block selects from four sets of error signals the set that should be used to control the field exciters. This block does not alter any of the error signals.

Figure 15 shows the field command override logic. Note that the two sides are treated separately and that there is a definite hierarchy. If the upper level supervisor is in the active mode, its field commands override all others. Next in the hierarchy are the lower level supervisor and reversal error signals. Because of logic in other parts of the master control unit, the lower level supervisor and dynamic control cannot both be in the active mode at the same time. For instance, during reversal the lower level supervisor is inhibited from performing a configuration change.

If all three control sections are in the passive mode, the error signals generated by the field command block are input to the exciter controls.

3.3.3 REVERSE Block

The reversal block contains the logic to decide whether or not a reversal is required. If it is determined that a reversal is called for, fixed programs are executed which direct the reversal process. Here the decision logic is given, however, the reversal programs which are based upon the analog simulation (see section ____) are only shown in outline form.

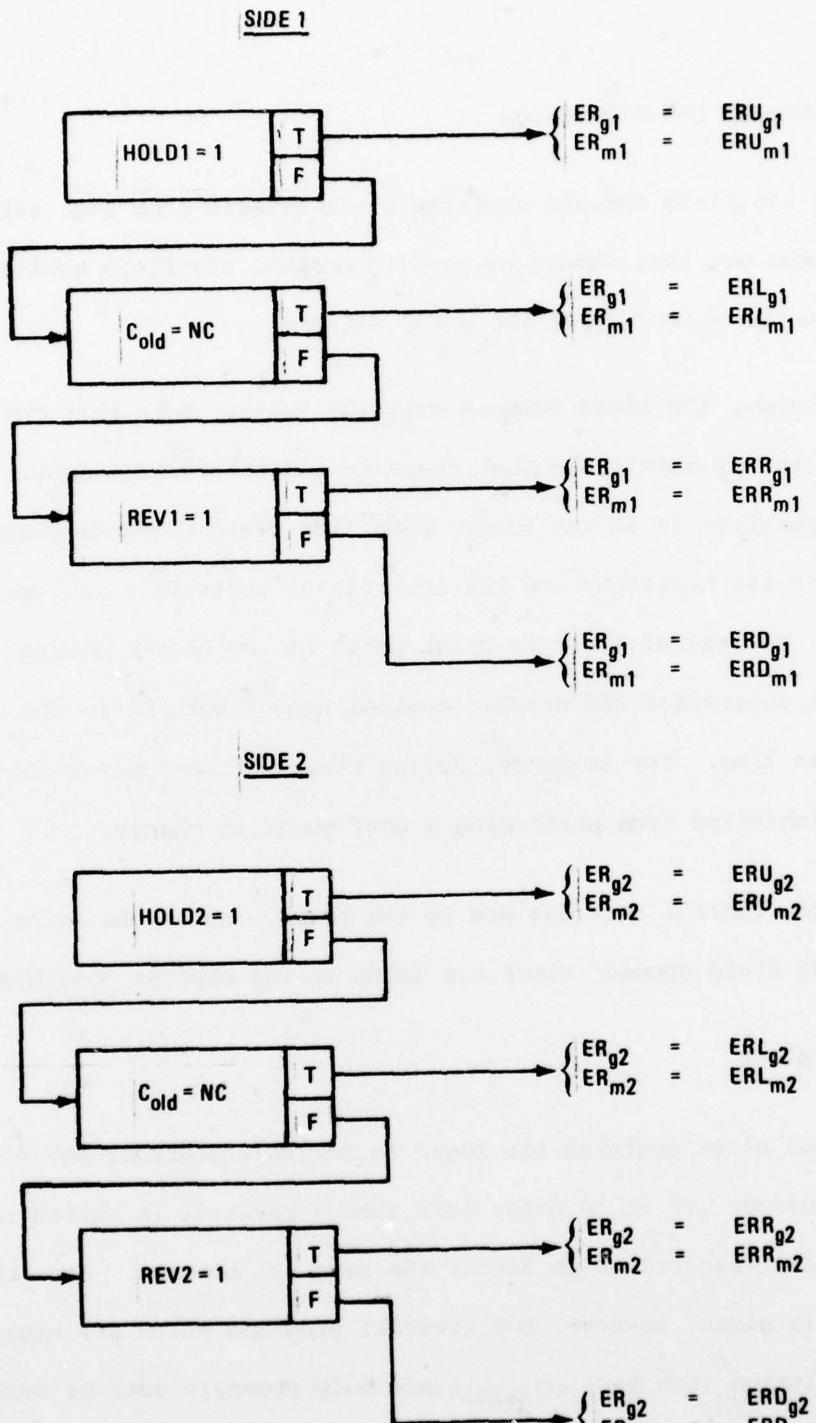


Figure 15 Field Command Override Logic

Figure 16 shows the logic which determines if a reversal is required (logical 1) or is not required (logical 0) as given by the parameters β_1 and β_2 which correspond to sides 1 and 2 respectively. In order for β_1 to be true, the following three conditions must be met:

1. The sign (i.e. plus or minus) of the torque reference and motor speed must be opposite to each other. This is the primary means of determining whether or not a reversal is required. The last two conditions are more or less just qualifiers which are often true.

2. The drive system must be in a configuration in which the load may be driven. This is an obvious qualification, but none the less, one which must be checked.

   In the quarter power configuration which only has one power circuit a reversal must be performed on both sides. Therefore, in the quarter power configuration, only the side with the largest torque reference absolute value is used to determine if a reversal is required.

3. The value of the torque reference must be outside of a small dead band which is established near zero. The purpose here is to negate undesirable reversals which could occur due to the uncertainty of the sign of the torque reference near the cross over point (i.e. ideally at zero torque reference).

The logic for β_2 is essentially a mirror image of that for β_1.

SIDE 1

$\{SIGN(\tau_{r1}) \neq SIGN(N_{m1})\}$
.AND.
$\{[(C_{old} = Q1).OR.(C_{old} = Q2)].AND.[|\tau_{r1}| \geq |\tau_{r2}|)]$
$.OR.[C_{old} = H1]$
$.OR.[C_{old} = H]$
$.OR.[C_{old} = F1]\}$
.AND.
$\{[\tau_{r1} > 0.01] .OR. [\tau_{r1} < -0.01]\}$

T $\longrightarrow \beta_1$

F

SIDE 2

$\{SIGN(\tau_{r2}) \neq SIGN(N_{m2})\}$
.AND.
$\{[(C_{old} = Q1).OR.(C_{old} = Q2)].AND.[|\tau_{r1}| < |\tau_{r2}|)]$
$.OR.[C_{old} = H1]$
$.OR.[C_{old} = H]$
$.OR.[C_{old} = F1]\}$
.AND.
$\{[\tau_{r2} > 0.01] .OR. [\tau_{r2} < -0.01]\}$

T $\longrightarrow \beta_2$

F

(REV1 = 1)
.OR.
(REV2 = 1)

T $\longrightarrow$ REV

F

Figure 16 Reversal Logic

There are four separate reversal programs: full power configuration, half power configuration sides 1 and 2, and quarter power configuration. Whenever β_1 or β_2 become true, one of these programs is executed. Figure 17 gives the general outline of the reversal programs. In the following paragraphs, some further explanatory notes are given.

At the start of a reversal program, the parameter REV1 is made true if a reversal is being performed on side 1. The same holds true for REV2 with respect to side 2. These two parameters cause the field commands generated by the reversal program(s) to be input to the exciter controls via the FIELD COMMAND OVERRIDE logic.

In addition, whenever REV1 or REV2 are true, REV is true which inhibits the lower level supervisory control from performing a transition.

Throughout steps 1, 2, and 3, the reversal process is aborted if the applicable β becomes false which indicates that a reversal is no longer required. If necessary, the armature circuit is reclosed under reversal program control. The parameter(s) REV1 and/or REV2 are reset to logical 0 which returns control of the fields to the FIELD COMMAND block.

Once step 4 is initiated, the reversal process is carried out to comcompletion with the sole exception being that if the upper level supervisory control changes from the passive to the active mode, the reversal program(s) on the side(s) affected is/are immediately terminated.

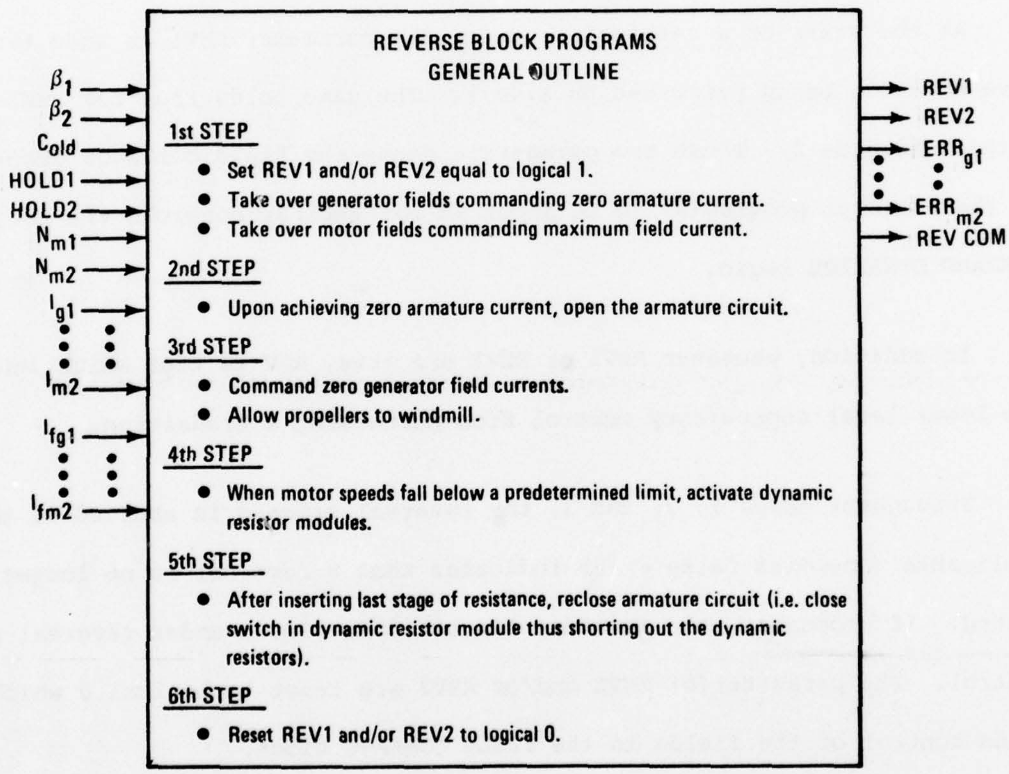


Figure 17 Reversal Programs

4. LOWER LEVEL SUPERVISORY CONTROL

4.1 Functions

The lower level supervisory control performs the functions of configuration control and generation of the speed references. For each prime mover/generator, the load is continuously monitored and a speed reference is sent to the test stand controls. This speed approximates the turbine reference speed used in the 40 khp/shaft system.

In the passive mode the switch positions are not changed. The lower level supervisor compares the operator selected configuration with the configuration in which the propulsion system is operating. If they differ, and the SEGMAG machines for the new configuration are available, the active mode is initiated and a transition is performed per a fixed program. This program takes over all field commands and executes a predetermined sequence of steps which include changes in the switch and circuit breaker commands.

4.2 Input/Output

Figure 18 shows the lower level supervisory control input and output. Also shown is a simplified block diagram which is described in the next section.

The input and output parameters are listed in Tables 9 through 15. The symbol and total number for each parameter is shown. Also, the type of signal is identified and a brief description of each is given.

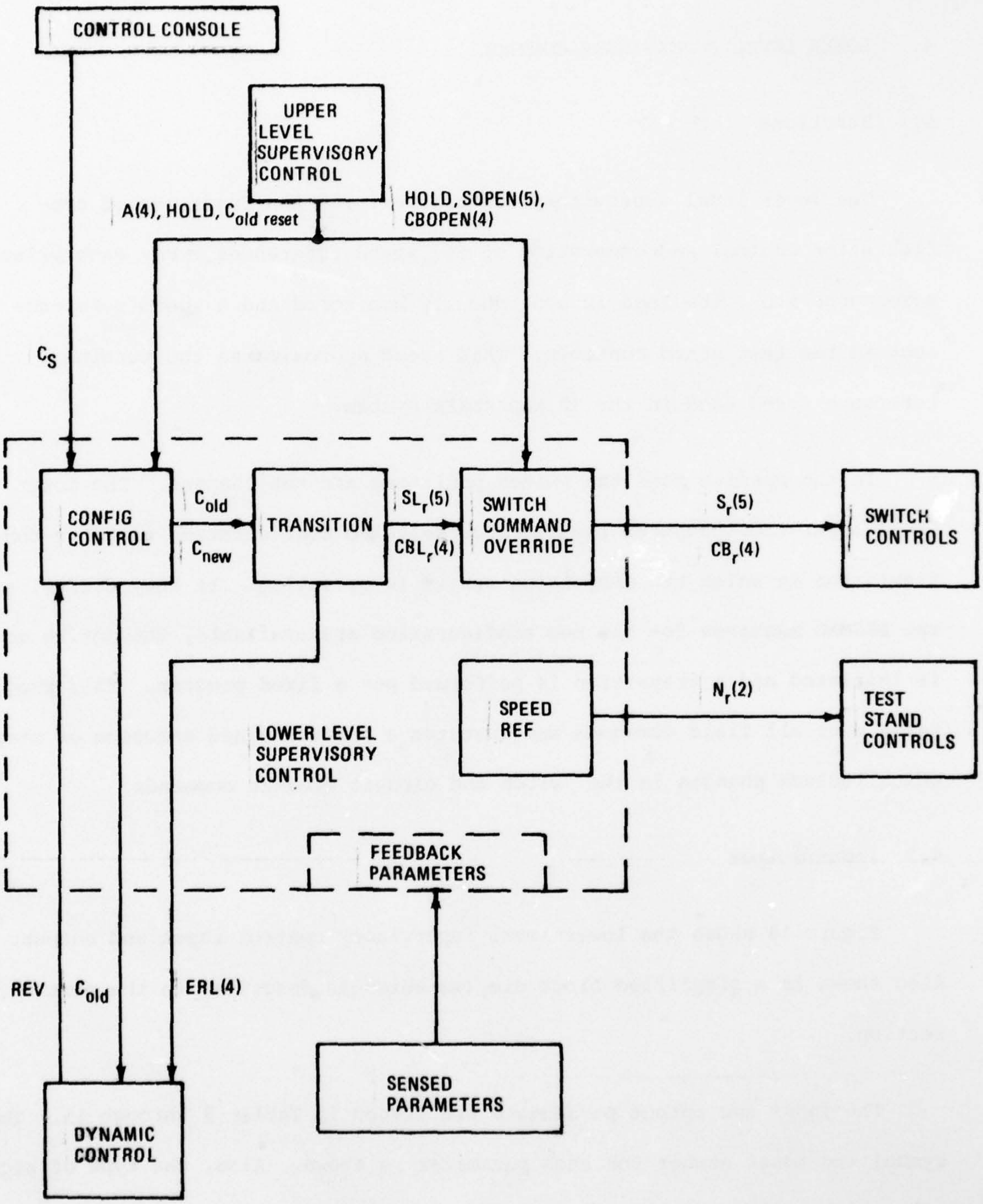


Figure 18 Lower Level Supervisory Control Input/Output and Block Diagram

Table 9 shows the console input which is the operator selected configuration. This may have any of eight values, F1, F2, H1, H2, H, Q1, Q2, and Z, which correspond to full power, half power, quarter power, and zero power configurations.

Table 9. Console Inputs to the Lower Level Supervisor

Symbol	Total Number	Type	Description
C_s	1	discrete variable	Gives the selected configuration

Table 10. Lower Level Supervisor Sensor Signals and Feedback Parameters

Sensor Signal Symbol	Feedback Parameter Symbol	Total Number	Type	Description
I_{gx}	I_{gx}	2	variable	Generator X current
V_{gx}	V_{gx}	2	variable	Generator X voltage
I_{fgx}	I_{fgx}	2	variable	Generator X field current
V_{mx}	V_{mx}	2	variable	Motor X voltage
I_{fmx}	I_{fmx}	2	variable	Motor X field current
SX	SX	5	logical	Switch X position
CBX	CBX	4	logical	Circuit breaker X position

Note: "X" in the sym ols has the values 1 thru "total number."

Table 11. Dynamic Control Input to the Lower Level Supervisor

Symbol	Total Number	Type	Description
REV	1	logical	During reversal, the dynamic control is in the active mode (logical 1).

Table 12. Upper Level Supervisor Inputs to the Lower Level Supervisor

Symbol	Total Number	Type	Description
(A) A_{g1} A_{g2} A_{m1} A_{m2}	4	logical	Gives whether a machine is available (logical 1) or is not available (logical 0) for inclusion in the drive system.
HOLD	1	logical	Upper level supervisor is in the passive mode (logical 0) or active mode (logical 1).
$C_{old\ reset}$	1	discrete variable	Gives configuration when upper level supervisor changes from the active to the passive mode.
(SOPEN) SXOPEN	5	logical	Each parameter commands switch X (or circuit breaker X) to open (logical 1) or not to change position (logical 0)
(CBOPEN) CBXOPEN	4	logical	

Table 13. Lower Level Supervisor Inputs to the Switch Controls

Symbol	Total Number	Type	Description
(S_r) SX_r	5	logical	Each reference commands switch X (or circuit breaker X) to be open (logical 0) or closed (logical 1).
(CB_r) CBX_r	4	logical	

Table 14. Lower Level Supervisor Inputs to the Test Stand Controls

Symbol	Total Number	Type	Description
(N_r)	2	variable	
N_{r1}			Speed reference 1
N_{r2}			Speed reference 2

Table 15. Lower Level Supervisor Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
C_{old}	1	discrete variable	Gives the configuration in which the system is operating. During transition, C_{old} has the value "NC."
(ERL) ERL_{g1} ERL_{g2} ERL_{m1} ERL_{m2}	4	variable	Field commands

Table 10 lists the 19 sensor signals which are also used directly as feedback signals by the lower level supervisor. The 5 switch signals and 4 circuit breaker signals are logical 0 in the open position and logical 1 in the closed position.

Table 11 shows the dynamic control input parameter REV. When a reversal is in progress, REV is true and the lower level supervisor is inhibited from performing a transition.

Table 12 lists the upper level supervisory control inputs. Four availability signals which correspond to the four SEGMAG machines indicate whether or not each is available for inclusion in the drive system. This information is used by the logic which controls the drive system configuration.

Whenever the upper level supervisor is in the active mode, the logical parameter HOLD is true which, among other things, places the switch and circuit breaker commands under the dictates of the upper level supervisor.

The parameter $C_{old\ reset}$ gives the configuration the drive system is in when the upper level supervisor returns to the passive mode.

Each of the five SOPEN parameters commands a switch *to open* when true, otherwise the switch position is not altered. The same holds true for the circuit breakers with respect to the four CBOPEN parameters.

Table 13 shows the five switch and four circuit breaker reference commands, which correspond to the switches S1 through S5 and circuit breakers CB1 through CB4. These signals are input to the switch controls. When true, a switch (or circuit breaker) is commanded to be closed, when false, a switch (or circuit breaker) is commanded to be open.

Table 14 shows the two speed reference signals which are input to the test stand controls.

Table 15 lists the inputs to the dynamic control section. The discrete variable C_{old} has the value "NC" during transition. Otherwise it indicates which configuration the system is operating in. Four field commands are also input to the dynamic control. These signals are only input to the exciter controls during transition.

4.3 Block Diagram

Following a brief explanation of the roll played by each of the four blocks in the lower level supervisory control section (Figure 18), a detailed description of the internal functioning of each is given.

In the passive mode, the CONFIG CONTROL block compares the operator selected configuration with the configuration the system is operating in. If these differ and the required machines are available, the configuration control triggers a transition and determines the new configuration in accordance with Figure 8. For instance, if the system were in the zero power configuration with G1, M1, and M2 available and the operator then selected full power configuration F1, the following would occur. The configuration control would first call for a change to the half power configuration H1. After this transition had been completed, it would trigger a change to the full power configuration F1.

As a final note, if a reversal is in progress, the configuration control is inhibited from calling for a transition.

The TRANSITION block contains fixed programs which perform configuration changes when triggered by the configuration control. During transition, these programs control the machine fields and change switch and circuit breaker positions. When not performing a transition, the switch reference signals are held static with one of two values, logical 0 or logical 1.

The SWITCH COMMAND OVERRIDE block contains the logic which allows the upper level supervisory control to override the switch and circuit breaker reference signals from the TRANSITION block.

The SPEED REF block generates the two speed reference signals which are input to the prime mover controls.

4.3.1 CONFIG CONTROL Block

Figure 19 shows a control diagram for the CONFIG CONTROL block. This portion of the lower level control decides which configuration the drive system should be operating in and orders transitions when necessary. From the console, the operator selects the value of C_S which is equal to any one of the eight possible power configurations.

The availability of the necessary generators and motors for the selected configuration, C_S, is checked. If satisfactory, the reference configuration parameter, C_{ref}, is set equal to C_S. If not satisfactory, another configuration is commanded, most often the zero power configuration, Z. Note that if a SEGMAG machine which is operating in the system has its availability signal changed from a logical 1 to 0, the drive system will be reconfigured taking that machine out of the drive system.

The value of C_{new} is a function of the parameters C_{ref} and C_{old} as given by the C_{new} matrix. As long as C_{ref} and C_{old} are equal, C_{new} is also of the same value and the lower level supervisory control remains in the passive mode.

If C_{ref} changes to a new value, C_{new} gives the configuration to which the system should be changed in accordance with Figure 8. If a reversal is not in progress (REV false), a transition is performed during which time C_{old} is set equal to NC.

Whenever the upper level supervisory control is in the active mode, HOLD is true and C_{old} is set equal to $C_{old\ reset}$. Furthermore, if a transition

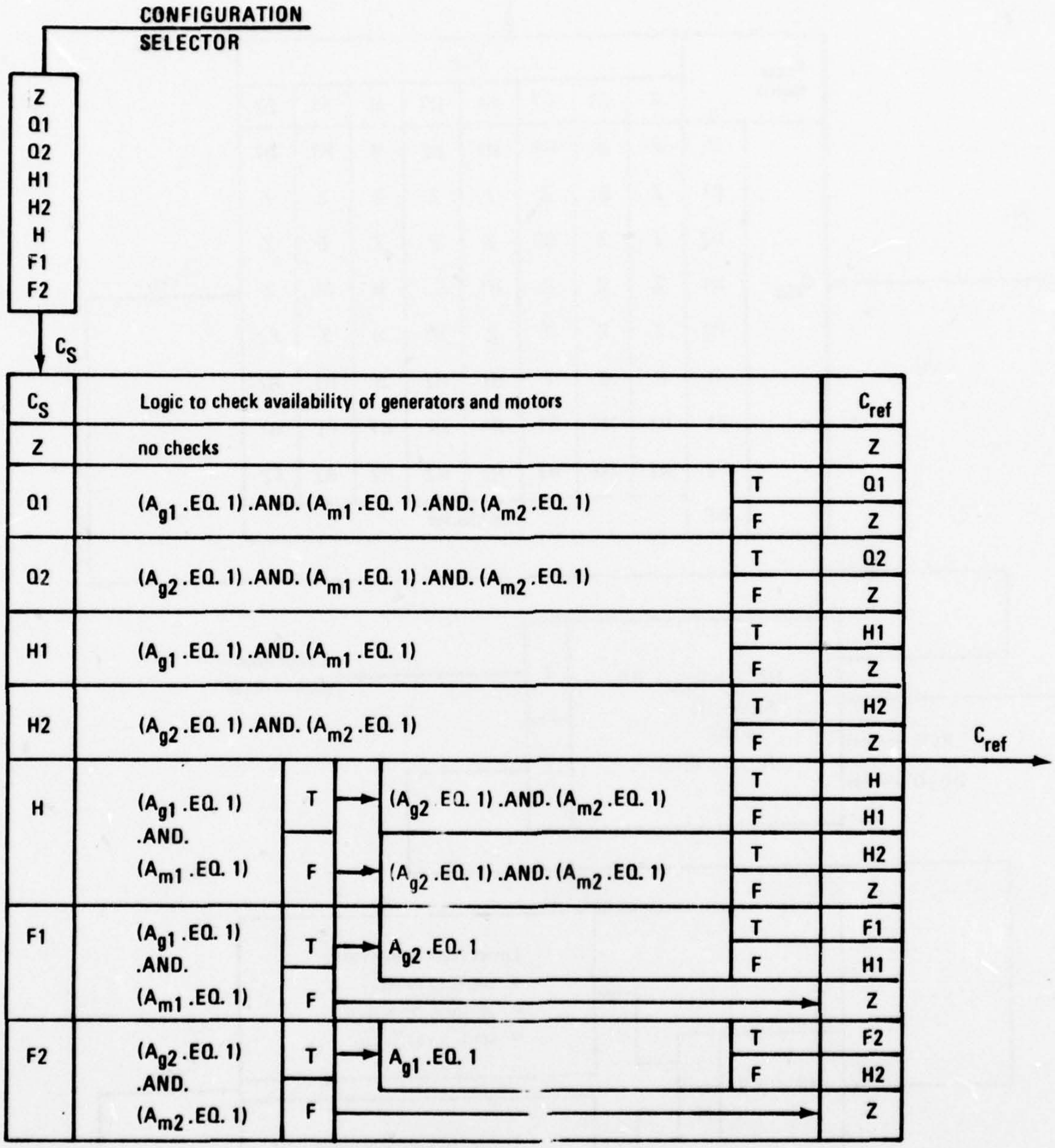
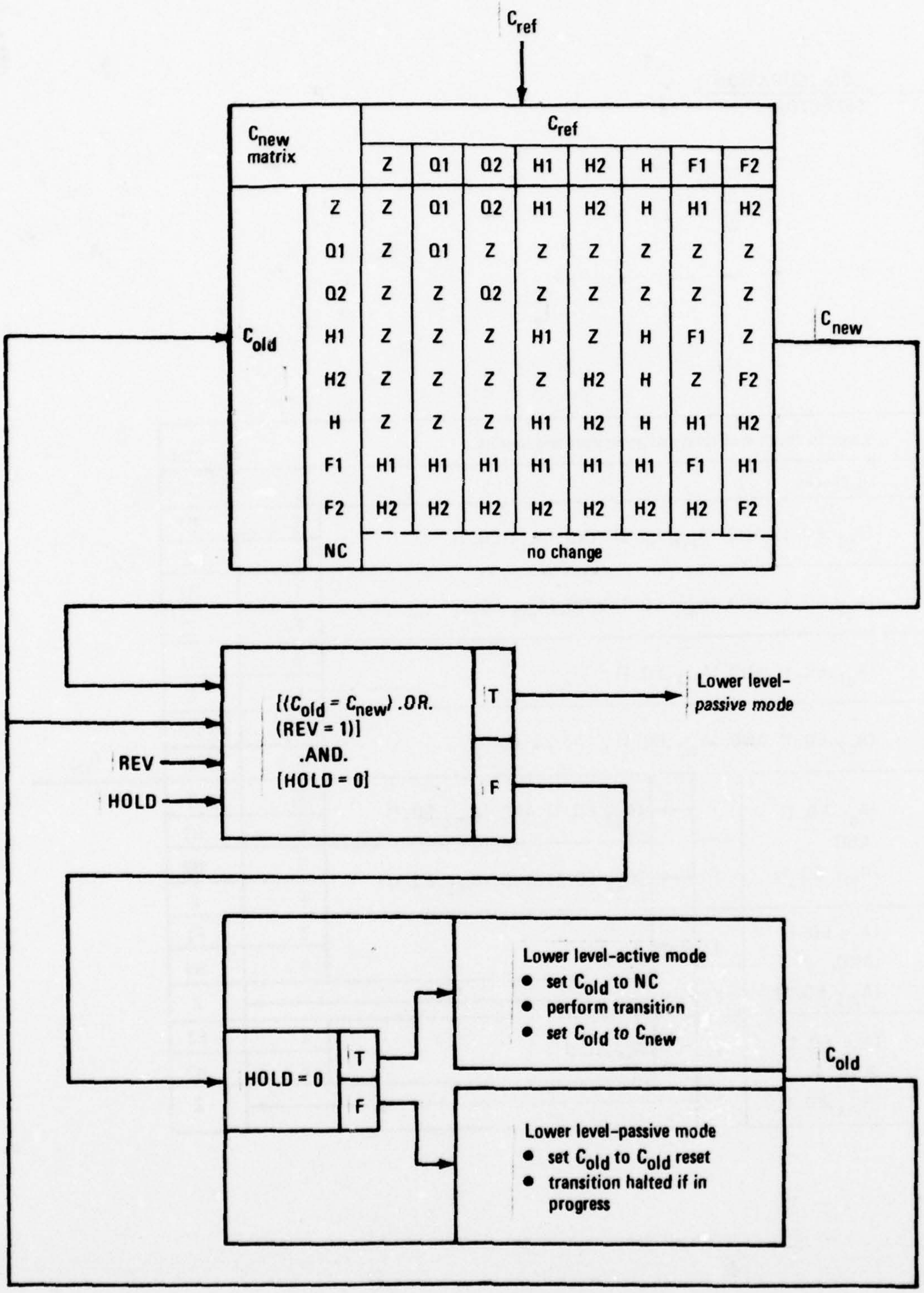


Figure 19a Configuration Control Diagram



C_{new} matrix	C_{ref}: Z	Q1	Q2	H1	H2	H	F1	F2
C_{old}: Z	Z	Q1	Q2	H1	H2	H	H1	H2
Q1	Z	Q1	Z	Z	Z	Z	Z	Z
Q2	Z	Z	Q2	Z	Z	Z	Z	Z
H1	Z	Z	Z	H1	Z	H	F1	Z
H2	Z	Z	Z	Z	H2	H	Z	F2
H	Z	Z	Z	H1	H2	H	H1	H2
F1	H1	H1	H1	H1	H1	H1	F1	H1
F2	H2	H2	H2	H2	H2	H2	H2	F2
NC	no change							

Figure 19b Configuration Control Diagram

were in progress, it would be terminated since the upper level supervisor takes over all field and switch commands.

4.3.2 TRANSITION Block

In carrying out a configuration change, a sequence of steps are taken, whereby certain conditions must be fulfilled before proceeding to the next step. The control system performs transitions by executing the appropriate built in program.

In the ensuing figures, a typical configuration change is given in outline form for each of the six basic transitions which occur between the zero and quarter power configurations, the zero and half power configurations, and the half and full power configurations.

Figure 20 shows the transition from the zero power configuration, Z, to the quarter power configuration, Q1.

Initially the drive system is operating in the zero power configuration. The configuration parameters, C_{old} and C_{new}, are both Z and, therefore, a transition is not yet called for. All of the armature circuit breakers and switches are open.

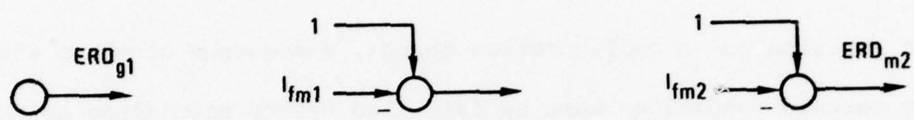
Step 1 is initiated when the parameter C_{new} is changed to Q1. Subsequently C_{old} is changed to NC and the exciter control inputs then originate in the lower level supervisory control. The make up of the error signals for the motors are left unaltered, however, the error signal for generator 3 is changed in such a manner that the generator field current, I_{fg1}, is

G1, M1, M2 standby $\xrightarrow{\text{transition}}$ G1, M1, M2 on line

INITIAL CONDITIONS

- $C_{new} = Z$, $C_{old} = Z$
- Switch position: all switches and circuit breakers open

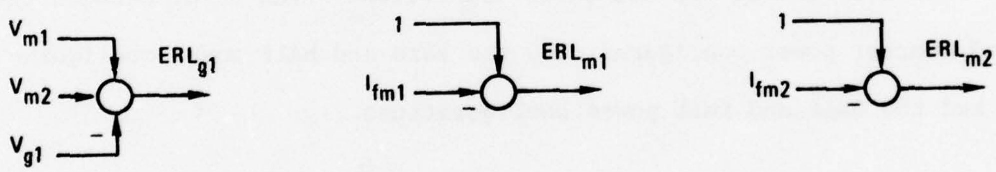
G1 M1 M2



STEP 1

- Condition: $C_{new} = Q1$
- C_{old} changed to NC
- $S1L_r$ and $S5L_r$ changed to logical 1

G1 M1 M2



STEP 2

- Conditions: $(|V_{m1} + V_{m2} - V_{g1}| < 0.01)$ .AND. (S1 = 1) .AND. (S5 = 1)
- $CB1L_r$, $CB3L_r$, and $CB4L_r$ changed to logical 1

STEP 3

- Conditions: CB1, CB3, CB4 = 1

G1	M1	M2
per Fig. 13	per Fig. 13	per Fig. 13

STEP 4

- Conditions: Change in makeup of error signals completed
- Change C_{old} to Q1

Figure 20 Transition, Zero Power (Z) to Quarter Power Configuration (Q1)

adjusted until the generator voltage equals the sum of the motor voltages. The switches S1 and S5 are commanded to close, but circuit breakers 1, 2, and 3 are left open and thus the armature circuit is not completed.

Step 2 is initiated when the switch position signals show that S1 and S5 are closed and the absolute value of generator 1 voltage minus the two motor voltages is less than or equal to 5V. Circuit breakers 1, 2, and 3 are commanded to close thus completing the armature circuit.

Step 3 is initiated when the feedback signals indicate that circuit breakers 1, 2, and 3 are closed. The make up of the error signals for generator 1 and both motors are changed to be in accordance with the field command diagram for the quarter power configuration, Figure 13.

Step 4 is initiated when the changes in the make up of the error signals have been completed. The parameter C_{old} is changed to Q1 and the transition is thus completed.

Figure 21 shows the transition from the quarter power configuration, Q1, to the zero power configuration, Z.

Initially the drive system is i the quarter power configuration. The configuration parameters, C_{old} and C_{new} are both equal to Q1. The circuit breakers CB1, CB2, and CB3 and switches S1 and S2 are closed. The make up of the error signal inputs to the generator and motor exciter controls are as shown in Figure 13.

G1, M1, M2 on line $\xrightarrow{\text{transition}}$ G1, M1, M2 off line

INITIAL CONDITIONS

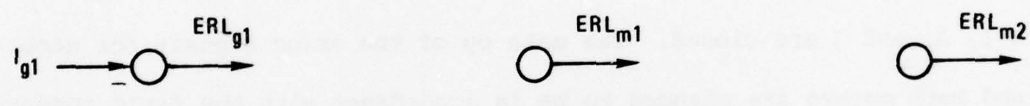
- $C_{new} = Q1$, $C_{old} = Q1$
- Switch positions: CB1, CB3, CB4, S1, and S5 closed/CB2, S2, S3, S4 open

G1	M1	M2
per Fig. 13	per Fig. 13	per Fig. 13

STEP 1

- Condition: $C_{new} = Z$
- C_{old} changed to NC

G1	M1	M2



STEP 2

- Condition: $|I_{g1}| < 0.01$
- $CB1L_r$, $CB3L_r$, and $CB4L_r$ changed to logical 0

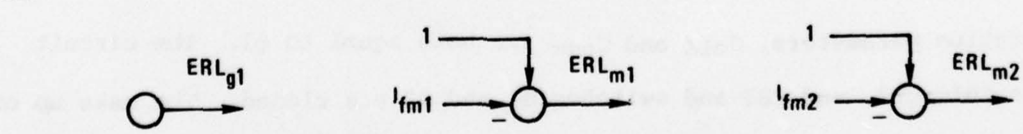
STEP 3

- Conditions: CB1, CB3, and CB4 = 0
- $S1L_r$ and $S5L_r$ changed to logical 0

STEP 4

- Conditions: S1 and S5 = 0

G1	M1	M2



STEP 5

- Conditions: Changes in makeup of error signals completed
- Change C_{old} to Z

Figure 21 Transition, Quarter Power (Q1) to Zero Power Configuration (Z)

Step 1 is initiated when C_{new} is changed to Z. Subsequently C_{old} is changed to NC. The circuit breaker positions and switch positions are left unchanged. The error signals for the motor fields, ERL_{m1} and ERL_{m2} are made zero, leaving the motor field currents fixed until such time that the error signals are again changed. The generator 1 error signal is changed as shown with the result that the generator field current is adjusted to produce zero armature current.

Step 2 is initiated when the absolute value of the generator armature current, I_{g1}, is no greater than 45A and circuit breakers 1, 3, and 4 are commanded to open.

Step 3 is initiated when the feedback signals indicate the CB1, CB3, and CB4 are open and thus the armature circuit is broken. The switches, S1 and S5 are commanded to open.

Step 4 is initiated when the switch position signals indicate that S1 and S5 are open and the error signals for generator 1 and the motors are changed to the zero power configuration.

Step 5 is initiated when the error signal changes have been completed and C_{old} is changed to Z.

Figure 22 shows the transition from the zero power configuration to the half power configuration, H1.

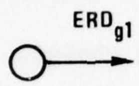
Initially the drive system is in the zero power configuration. All circuit breakers and switches are open.

G1, M1 standby $\xrightarrow{\text{transition}}$ G1, M1 on line

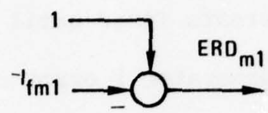
INITIAL CONDITIONS

- $C_{new} = Z$, $C_{old} = Z$
- Switch positions: all switches and circuit breakers open

G1



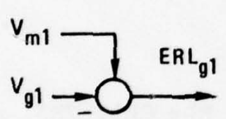
M1



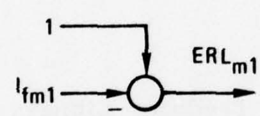
STEP 1

- Condition: $C_{new} = H1$
- C_{old} changed to NC
- $S3L_r$ changed to logical 1

G1



M1



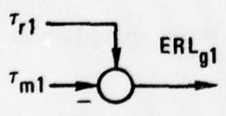
STEP 2

- Conditions: $(|V_{m1} - V_{g1}| < 0.01)$ .AND. $(S3 = 1)$
- $CB1L_r$ and $CB3L_r$ changed to logical 1

STEP 3

- Conditions: CB1 and CB3 = 1

G1



M1

no change

STEP 4

- Condition: Change in makeup of error signal ERL_{g1} completed
- Change C_{old} to HI

Figure 3.6-22 Transition, Zero Power to Idle Power Configuration

Step 1 is initiated when C_{new} is changed from Z to H1. Subsequently C_{old} is changed from Z to NC. The switch, S3, is commanded to close, however, the armature circuit is not completed since CB1 and CB3 are left open. The error signal for generator 1 is changed as shown with the result that the generator field current, I_{fg1}, is adjusted to produce a generator voltage which matches the motor voltage. The make up of the error signal for motor 1 is left unchanged since it is the same in the zero and half power configurations.

Step 2 is initiated when the absolute value of the difference of the motor and generator voltages is less than or equal to 5V. Also, the feedback signals indicate that S3 is closed. The circuit breakers CB1 and CB3 are commanded to close.

Step 3 is initiated when CB1 and CB3 are closed. The error signal for generatr 1 is changed to reflect the half power configuration.

Step 4 is initiated when the error signal change has been completed. C_{old} is changed to H1.

Figure 23 shows the transition rom the half power configuration, H1, to the zero power configuration.

Initially the drive system is in half power configuration H1. Circuit breakers 1 and 3 and switch 3 are closed.

Step 1 is initiated when C_{new} is changed to Z. Subsequently C_{old} is changed to NC. The error signal for generator 1 is changed as shown with the

G1, M1 on line $\xrightarrow{\text{transition}}$ G1, M1 off line

INITIAL CONDITIONS

- C_{new} = HI, Cold = HI
- Switch positions: CB1, CB3, and S3 closed/CB2, CB4, S1, S2, S4, and S5 open

G1 **M1**

STEP 1

- Condition: C_{new} = Z
- C_{old} changed to NC

G1 **M1**

STEP 2

- Condition: $|I_{g1}| < 0.01$
- CB1 L_r and CB3 L_r changed to logical 0

STEP 3

- Conditions: CB1 and CB3 = 0
- S3 L_r changed to logical 0

STEP 4

- Condition: S3 = 0

G1 **M1**

no change

STEP 5

- Condition: Change in makeup of error signal ERL_{g1} completed
- Change C_{old} to Z

Figure 23 Transition, Half Power (HI) to Zero Power Configurations (Z)

result that the generator field current, I_{fg1}, is adjusted to give zero armature current.

Step 2 is initiated when the absolute value of the armature current is no greater than 45A. The circuit breakers 1 and 3 are commanded to open.

Step 3 is initiated when it is established that circuit breakers 1 and 3 are open as shown by the circuit breaker position signals. The switch, S3, is commanded to open.

Step 4 is initiated when the feedback signals indicate that switch 3 is open. The error signal for generator 1 is changed to zero.

Step 5 is initiated when error signal for generator 1 has been changed. C_{old} is changed to Z which completes the transition.

Figure 24 shows the transition from half power configuration H1 to full power configuration F1. The side 1 generator and motor operate in the drive system before, during, and after transition. Further, the make up of their error signals remain unchanged. The generator on the other side, G2, is to be paralleled with G1.

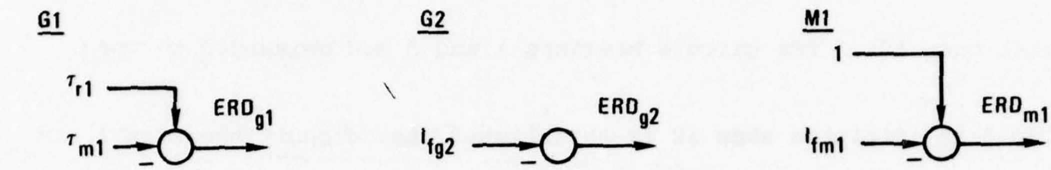
Initially C_{old} and C_{new} are both equal to H1. Generator 2 is available, but not operating in the drive system. Switch S3 and circuit breakers CB1 and CB3 are closed.

Step 1 is initiated when C_{new} is changed to F1. Subsequently C_{old} is changed to NC. The command to close switches S1 and S2 is given. The error

G1, M1 on line $\xrightarrow{\text{transition}}$ G1, G2, M1 on line
G2 standby

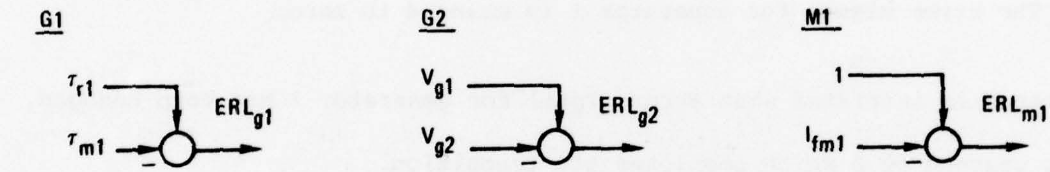
INITIAL CONDITIONS

- C_{new} = HI, C_{old} = HI
- Switch positions: CB1, CB3, and S3 closed/CB2, CB4, S1, S2, S4, and S5 open



STEP 1

- *Condition:* C_{new} = F1
- C_{old} changed to NC
- $S1L_r$ and $S2L_r$ changed to logical 1

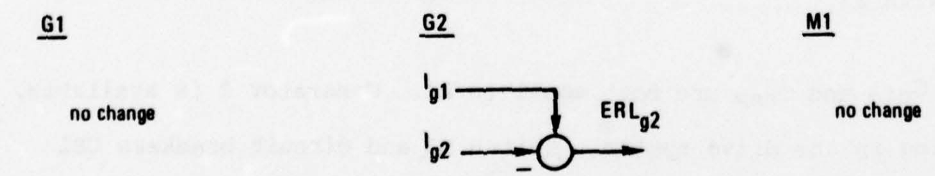


STEP 2

- Conditions: $(|V_{g1} - V_{g2}| < 0.01)$ .AND. (S1 = 1) .AND. (S2 = 1)
- $CB2L_r$ changed to logical 1

STEP 3

- Condition: CB2 = 1



STEP 4

- Condition: Change in makeup of error signal ERL_{g2} completed
- Change C_{old} to F1

Figure 24 Transition, Half Power (HI) to Full Power Configuration (FI)

signal for generator 2 is changed such that I_{fg2} is regulated to match the voltage of generator 2 with the voltage of generator 1.

Step 2 is initiated when the voltage difference between the two generators is within the range of -5V to +5V. It is also established that switches S1 and S2 are closed. Circuit breaker CBY is commanded to close which will complete the parallel connection of generator 2.

Step 3 is initiated when the feedback signal from circuit breaker 2 indicates that it is in the closed position. The error signal for generator 2 is changed such that it strives to balance the current between the two generators.

Step 4 is initiated when the error signal change has been completed and C_{old} is changed to F1.

Figure 25 shows the transition from full power configuration F1 to half power configuration H1. Side 1 remains unchanged. The generator on the other side, side 2, is taken out of the drive system.

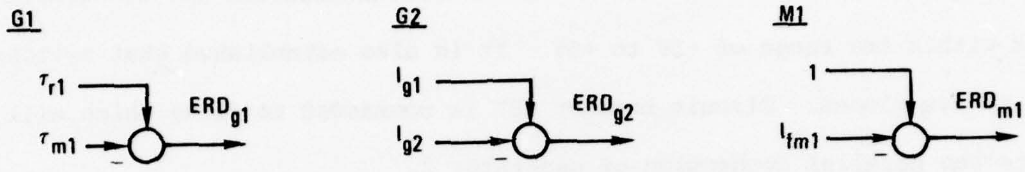
Initially C_{old} and C_{new} are both equal to F1 and the two generators, operating in parallel, are providing power to motor 1.

Step 1 is initiated when C_{new} is changed to H1 and C_{old} is changed to NC. The error signal for generator 2 is changed to H1 and C_{old} is changed with the result that the field current, I_{fg2}, is adjusted such generator 2 produces zero current.

G1, G2, M1 on line $\xrightarrow{\text{transition}}$ G1, M1 on line
G2 off line

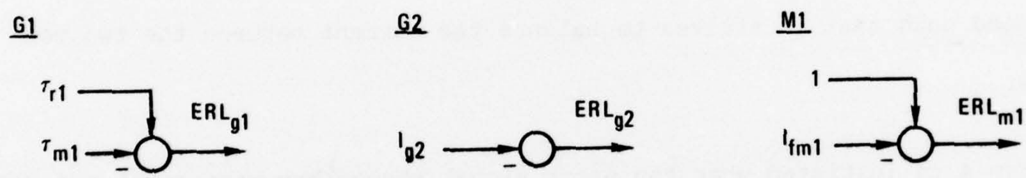
INITIAL CONDITIONS

- C_{new} = F1, C_{old} = F1
- Switch positions: CB1, CB2, CB3, S1, S2, and S3 closed/CB4, S4, and S5 open



STEP 1

- Condition: C_{new} = HI
- C_{old} changed to NC



STEP 2

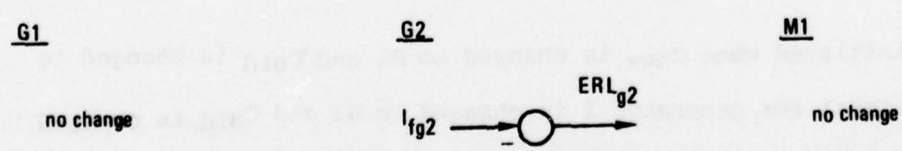
- Condition: $|I_{g2}| < 0.01$
- CB2L_r changed to logical 0

STEP 3

- Condition: CB2 = 0
- S1L_r and S2L_r changed to logical 0

STEP 4

- Condition: S1 and S2 = 0



STEP 5

- Condition: G2 off line
- Change C_{old} to HI

Figure 25 Transition, Full Power (FI) to Half Power Configuration (HI)

Step 2 is initiated when the absolute value of the current through generator 2 is less than or equal to 45A and circuit breaker 2, CB2, is commanded to open.

Step 3 is initiated when the feedback position signal from CB2 indicates that this circuit breaker is open and the switches S1 and S2 are commanded to open.

Step 4 is initiated when it is established that the switches S1 and S2 are open and generator 2 is taken off line.

Step 5 is initiated when it is determined that G2 is off line and C_{old} is changed to H1.

4.3.3 SWITCH COMMAND OVERRIDE Block

The logic for the SWITCH COMMAND OVERRIDE block is shown in Figure 26. The following description which uses switch 1 as an example applies equally to each of the 5 switches and 4 circuit breakers.

When the upper level supervisory control section is in the passive mode (HOLD = 0), the switch reference command, $S1_r$, is equal to the reference generated by the lower level supervisor, $S1L_r$.

When the upper level supervisor is in the active mode, the parameter HOLD is true (logical 1). Two options are then available to the upper level supervisor. Either the switch reference command, $S1_r$, is left unchanged or, if it is true, switch 1 may be commanded to open by making S1OPEN true. Note

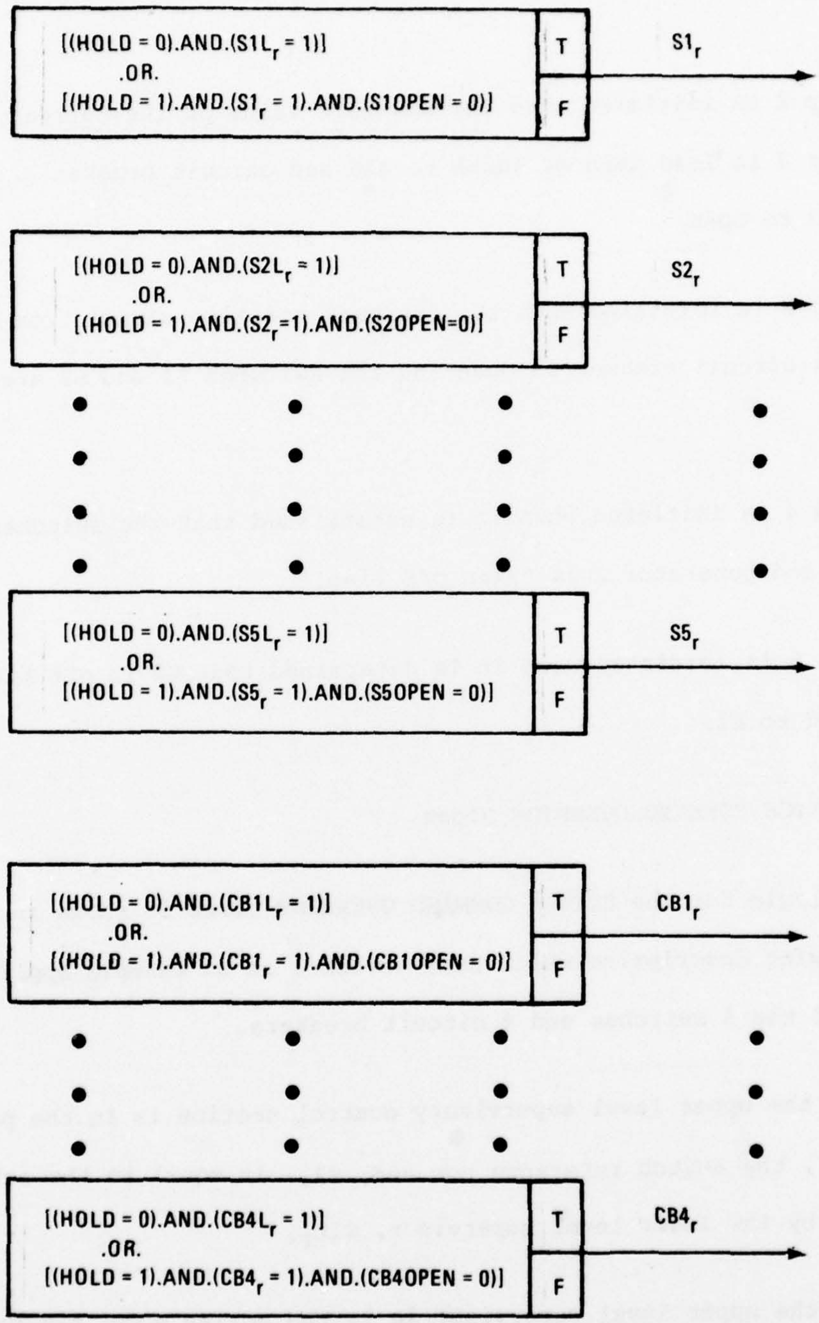


Figure 26 Switch Command Override Logic

that the upper level supervisor can not command an open switch to close since this capability is not needed in order to fulfill its tasks.

4.3.4 SPEED REF Block

For the 40 khp/shaft propulsion system, the gas turbines operate at the value given by the speed reference which represents the point of minimum specific fuel consumption. For the 3 khp/shaft drive, a similar speed reference is generated, the purpose being to prove the controls concept rather than to minimize the prime mover fuel consumption.

A speed reference signal is generated for each prime mover. Each of the signals is input to the prime mover controls which strive to match the prime mover speed with the reference speed. In the following, only the speed reference for prime mover 1 is described, the other speed reference being similar in make up.

Figure 27 illustrates the manner in which speed reference 1 is generated. For the moment, assume that the generator field current, I_{fg1}, is within the range of $-\gamma_1$ to $+\gamma_1$ and thus the output of the top function block is 1 and the logic block below is false.

As shown, the generator output power, P_{g1}, is calculated by taking the product of the generator current and generator voltage. From this, the optimum speed, N_{opt1}, is determined.

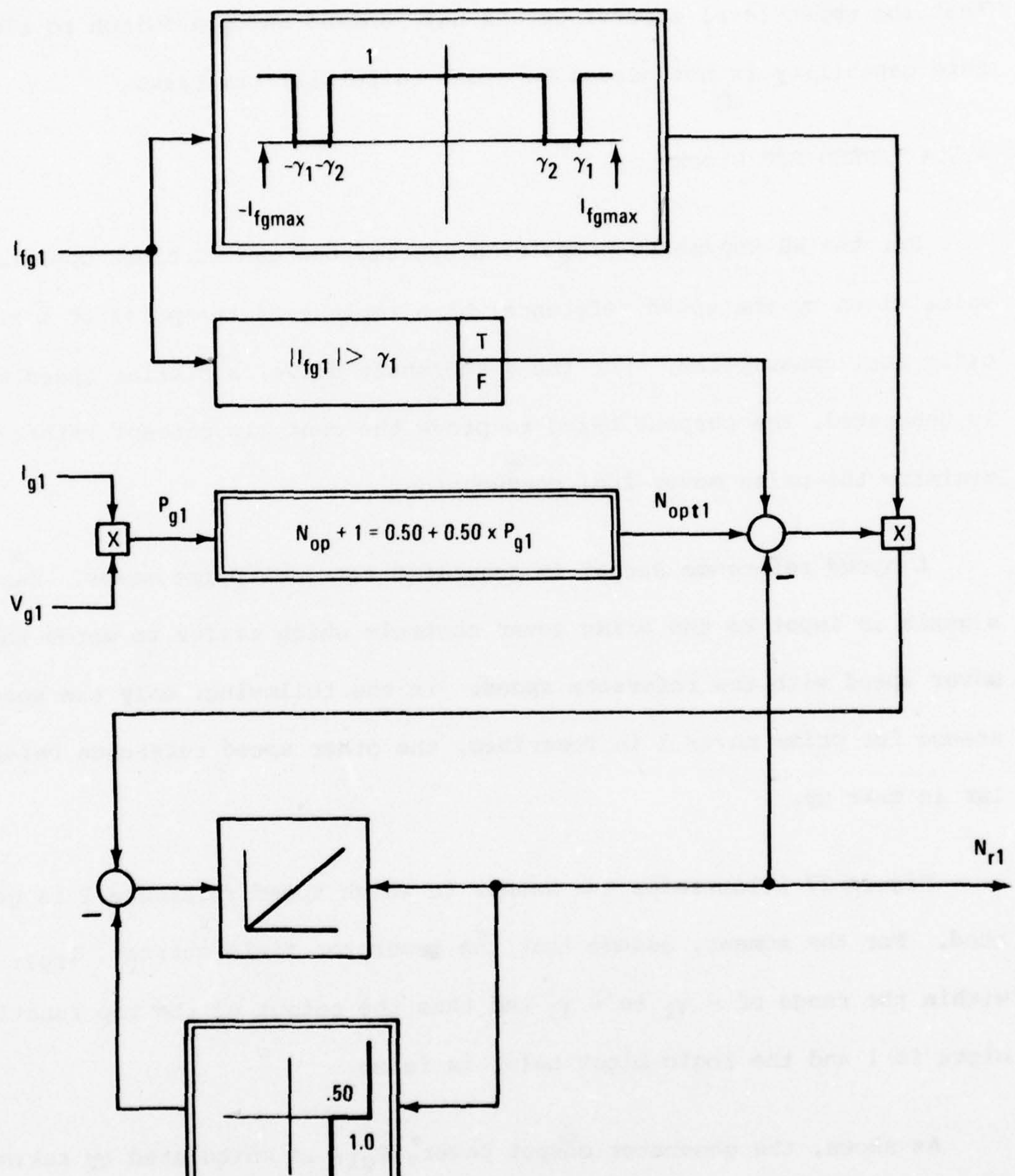


Figure 27 Speed Reference Control Diagram

At zero generator power output this is the approximate idle speed of a power turbine, 0.50 p.u. (1800 rev/min). At base operating conditions (P_{g1} = 1.0 p.u. = 2237 kW) this speed is 1.0 p.u. (3600 rev/min).

Now, the roll played by the top function block and the logic block below it will be discussed. It can happen that the generator becomes field current limited and therefore cannot meet its output requirements if turning at the optimum speed.

This can occur for instance when trying to parallel a generator on standby with one which is powering a motor at high power levels. At idle speed (1800 rev/min), the maximum generator voltage is about 280 V. A generator operating in the half power configuration at rated power would produce power at 500 V. In order to parallel machines under these conditions, it is necessary to increase the speed of the generator on standby above the optimum speed.

When the generator field current is greater than Υ_1, the logic block is true which results in increasing the reference speed. If, as the prime mover accelerates, the generator output requirements are achieved, the generator field will start to decrease. For stability, a small dead band between generator field values of Υ_1 and Υ_2 is incorporated, i.e. the speed reference is held constant whenever the generator field is within this range. As shown, this also holds for reversed generator fields. The values of Υ_1 and Υ_2 would be very close to I_{fgmax} which is the maximum attainable generator field current (approximately 1.12 p.u.).

5. UPPER LEVEL SUPERVISORY CONTROL

5.1 Functions

The most important functions performed by the upper level supervisory control are of the conditional rather than continuous type. In the passive mode, the drive system and control system including control console inputs are monitored for the occurrence of five categories of conditions which are anticipated to arise infrequently.

In the event that one of these conditions occurs, the upper level supervisor triggers a corresponding command. Once triggered, the upper level takes over control of the system (active mode) and performs a sequence of steps which result in the upper level returning to the passive mode and thus, returning control to the lower level supervisory and dynamic controls.

The following is a list of the five categories of conditions with a brief description of each.

<u>START</u>

The start command readies the drive system for operation. Every time the control system power is turned on, the starting sequence must be carried out before commencing with operation under the lower level supervisory and dynamic controls. During start, the proper initial values are given to the various controller logic signals. Also, it is insured that all switches and circuit breakers are open.

STOP

The stop command provides for an orderly shut down of the drive system. At the end of the stopping sequence, all switches and circuit breakers are open, the SEGMAG machine field currents are zero, and the prime movers are commanded not to drive the SEGMAG generators.

On a routine basis, upon completing a test the stop command would be given. After the sequence has been completed, the control system power may be turned off.

RESTART

The restart command interrupts the lower level supervisory and dynamic controls and places these controls and the drive system in the states they would have at the end of the starting sequence. The purpose of the restart cycle is to regain proper control in the event of a minor malfunction. This could be caused by such things as a transducer failure, an improbable operating condition that "locked-up" the lower level or dynamic control, etc.

EMER

Emergency conditions are any or all of the conditions which require immediate and rapid shut down of the drive system with the exception of electrical faults in the SEGMAG armature circuit(s). An emergency condition could be a machine overspeed, loss of lube oil pressure, etc. The emergency command immediately signals the prime mover controls to

rapidly shut down the prime movers. After a time delay, the emergency shut down sequence commands zero armature current, opens the switches and circuit breakers, and deenergizes the SEGMAG machine fields.

The armature circuit is not broken immediately due to two reasons: 1) it places unnecessary stress on the components and 2) in some situations it could be undesirable (e.g. overspeed due to a sudden loss of load).

FAULT

The fault command simultaneously deenergizes the fields of the SEGMAG machines rapidly, and signals the prime mover controls to quickly shutdown the prime movers.

Any of the five commands described above may be activated by the operator from the control console. In monitoring the drive system, the upper level supervisory control activates the RESTART, EMER, or FAULT commands upon detecting the need to take corrective action. An important feature of the control system is that when the drive is in the split plant mode, the two sides are treated independently of one another. In a ship board application, a side which was operating normally would not be shut down when emergency conditions were encountered on the other side. This same feature is also incorporated in the control system for the demonstration unit.

In addition to the conditional control functions given above, the upper level supervisor also provides permissives to the prime mover controls. In order for the prime movers to be allowed to run, certain conditions must be met, e.g. the lube oil systems must be operating.

5.2 Input/Output

Figure 28 shows the upper level supervisory control input and output. Also shown is a simplified block diagram and the flow of most of the interconnecting signal paths is indicated. The blocks are described in section 5.3 and the logic for each is given in section 5.4.

The input and output parameters are listed in tables 16 through 22. The symbol and total number for each parameter is shown. Also, the type of signal (i.e. logical, variable, etc.) and a brief description of each parameter is given.

Table 16 lists the nine inputs from the console. These are all logical signals and except for the four permissive signals, they are activated by normally open (N.O., logical 0) push buttons. The $START_{con}$ and $STOP_{con}$ inputs to the upper level are used for startup and normal shutdown of the system.

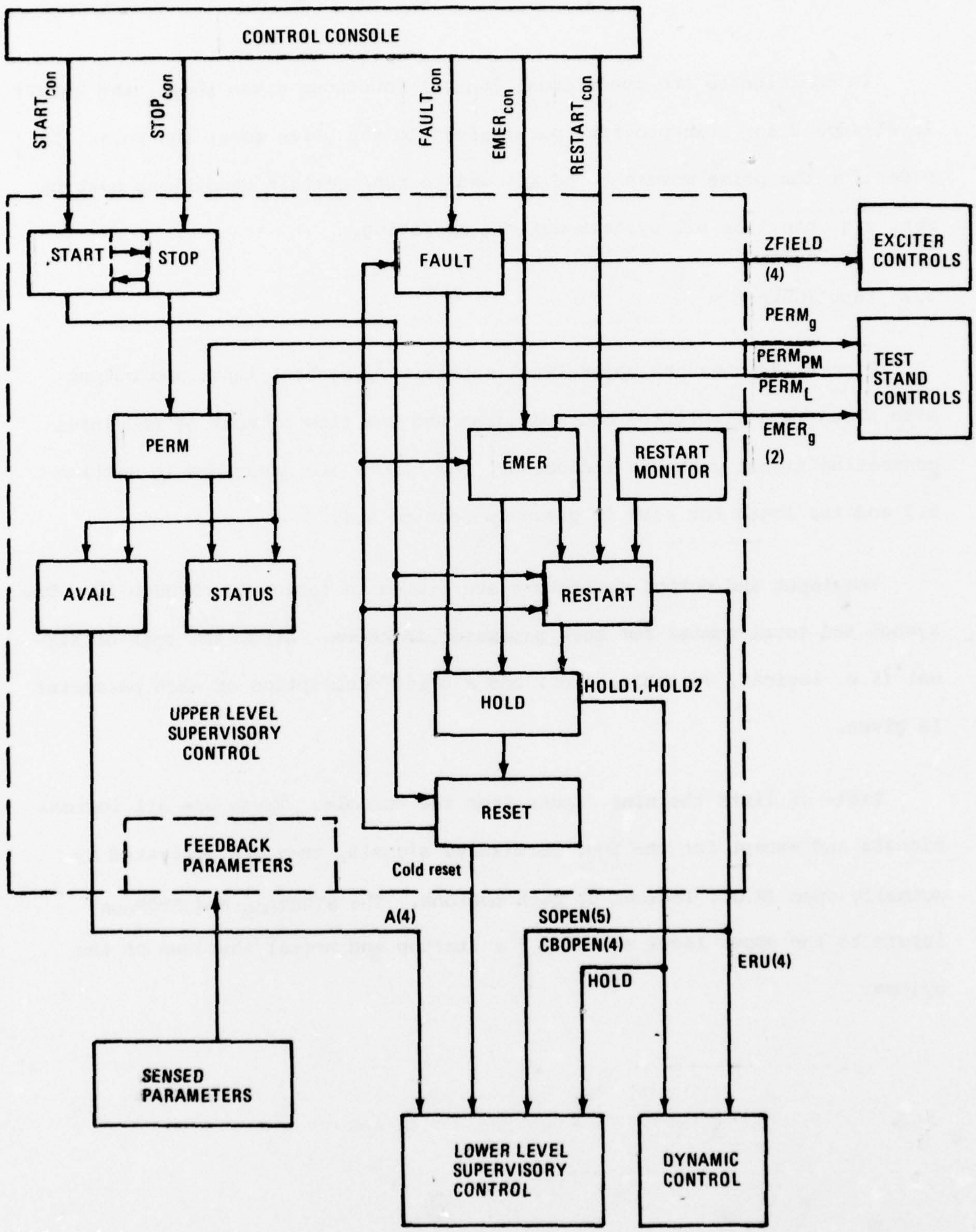


Figure 28 Upper Level Supervisory Control Input/Output and Block Diagram

Table 16. Console Inputs to the Upper Level Supervisor

Symbol	Total Number	Type	Description
$START_{con}$	1	logical	After energizing the control system, pushing the start console button (N.O/ logical 0) prepares the control and drive systems for operation and then releases control to the lower level supervisory and dynamic controls. Also, after a fault, emergency or restart cycle, this button must be pushed in order to return control to the lower level supervisor and dynamic control sections.
$STOP_{con}$	1	logical	Pushing the stop console button (N.O.) removes control from the lower level supervisory and dynamic controls and shuts down the drive system, leaving all switches and circuit breakers open.
$(PERM_{con})$ $PERM_{cong1}$ $PERM_{cong2}$ $PERM_{conm1}$ $PERM_{conm2}$	4	logical	Each permissive switch allows the operator to make a SEGMAG machine not available (logical 0). A closed switch (logical 1), along with other conditions, is required to make a machine available.
$FAULT_{con}$	1	logical	Pushing the fault button (N.O.) rapidly deenergizes all SEGMAG machine fields.

Table 16. Console Inputs to the Upper Level Supervisor (Continued)

Symbol	Total Number	Type	Description
$EMER_{con}$	1	logical	Pushing the emergency button (N.O.) commands a rapid shut-down of the drive system, but does not quickly deenergize the fields.
$RESTART_{con}$	1	logical	Pushing the restart button (N.O.) places the system in the same state as at the end of the starting cycle (idle configuration)

Table 17. Upper Level Supervisor Inputs to the Exciter Controls

Symbol	Total Number	Type	Description
(ZFIELD) $ZFIELD_{g1}$ $ZFIELD_{g2}$ $ZFIELD_{m1}$ $ZFIELD_{m2}$	4	logical	When the zero field command is given (logical 1) to an exciter, the field is to be rapidly deenergized.

Table 18. Upper Level Supervisor Feedback Parameters

Symbol	Total Number	Type	Description
SX	5	logical	Switch-x position, open-logical 0/closed-logical 1
CBX	4	logical	Circuit breaker-x position
N_{gx}	2	variable	Generator-x speed
I_{gx}	2	variable	Generator-x current
N_{mx}	2	variable	Motor-x speed
I_{mx}	2	variable	Motor-x current
NMX	2	integer (2 value)	Motor-x rotational direction: positive is +1, negative is -1
OIL_{gx}	2	logical	Generator-x lube oil status (sufficient for operation, logical 1/insufficient, logical 0)
OIL_{mx}	2	logical	Motor-x lube oil status
$EXCIT_{gx}$	2	logical	Generator exciter-x is (logical 1) or is not (logical 0) energized
$EXCIT_{mx}$	2	logical	Motor exciter-x energized
$CO2_{gx}$	2	logical	Generator-x CO_2 system status
$CO2_{mx}$	2	logical	Motor-x CO_2 system status
$H2O_{gx}$	2	logical	Generator-x H_2O system status
$H2O_{mx}$	2	logical	Motor-x H_2O system status

Notes: 1) "X" in the symbols has the values 1 thru the "total number".

2) The first 17 symbols (SX thru I_{mx}) are sensor signals which are used directly as feedback parameters. The sensor signals and logic required for the last 16 feedback parameters (OIL_{gx} thru $H2O_{mx}$) are to be determined.

Table 19. Upper Level Supervisor Inputs to the Lower Level Supervisor

Symbol	Total Number	Type	Description
(A) A_{g1} A_{g2} A_{m1} A_{m2}	4	logical	Gives whether a machine is available (logical 1) or is not available (logical 0) for inclusion in the drive system.
HOLD	1	logical	Upper level supervisor is in the passive mode (logical 0) or active mode (logical 1).
$C_{old\ reset}$	1	discrete variable	Gives configuration when upper level supervisor changes from the active to the passive mode.
(SOPEN) SXOPEN	5	logical	Each parameter commands switch X to open (logical 1) or not to change position (logical 0)
(CBOPEN) CBXOPEN	4	logical	Each parameter commands circuit breaker x to open or not to change position.

Table 20. Upper Level Supervisor Inputs to the Dynamic Control

Symbol	Total Number	Type	Description
HOLD1	1	logical	Upper level is in the passive mode (logical 0) or active mode (logical 1) with respect to side 1.
HOLD2	1	logical	Upper level is in the passive or active mode with respect to side 2.
(ERU) ERU_{g1} ERU_{g2} ERU_{m1} ERU_{m2}	4	variable	Field commands-only used when upper level is in the active mode.

Table 21. Upper Level Supervisor Inputs to the Test Stand Controls

Symbol	Total Number	Type	Description
($EMER_g$) $EMER_{g1}$ $EMER_{g2}$	2	logical	When the emergency command is given (logical 1), the appropriate prime mover(s) is/are to be rapidly shut down.
($PERM_g$) $PERM_{g1}$ $PERM_{g2}$	2	logical	Each generator permissive informs the prime mover controls if a generator may be driven (logical 1) or not (logical 0).

Table 22. Test Stand Control Inputs to the Upper Level Supervisor

Symbol	Total Number	Type	Description
($PERM_{PM}$) $PERM_{PM1}$ $PERM_{PM2}$	2	logical	Each prime mover permissive informs the SEGMAG control system if a prime mover is capable of driving a generator (logical 1) or not (logical 0).
($PERM_L$) $PERM_{L1}$ $PERM_{L2}$	2	logical	Each load permissive informs the SEGMAG control if a load device is capable of absorbing power from a motor (logical 1) or not (logical 0).

A permissive switch is located at the console for each of the four SEGMAG machines. In the off position (logical 0) the machine is not allowed to be driven either mechanically by a prime mover or electrically by other parts of the SEGMAG system. An on position (logical 1) is one of several conditions that must be met before a generator, or motor, may be operated as part of the drive system.

Part of the upper level control monitors pertinent drive system feedback parameters and upon sensing a condition requiring corrective action, a fault, emergency, or restart cycle is initiated automatically. As a backup, these same cycles may also be commanded by the operator by pushing the appropriate console button. At the end of any of these cycles all switches and circuit breakers are open and the prime movers are not allowed to drive the generators. After the cause of the condition requiring corrective action has subsided, the drive system continues to be inhibited from operating until the $START_{con}$ command is given by the operator at the console.

Table 17 lists the four exciter control inputs from the upper level which are activated under fault conditions. When ZFIELD is changed to logical 1, the field of the SEGMAG machine is to be rapidly deenergized.

Table 18 lists the 35 feedback parameters required by the upper level. The first 17 comprise the sensor signals for the switch and circuit breaker positions, the machine rotational speeds, and the machine armature currents.

The next two feedback parameters, NM1 and NM2, give the motor rotational directions.

The last 16 feedback parameters are logical signals which are determined by monitoring the machine auxiliaries: The four parameters must be true (logical 1) for a machine to be available for inclusion in the drive system. The logic and sensor signals required to generate these feedback signals have yet to be determined.

Table 19 lists the lower level supervisor inputs from the upper level supervisor. Four availability signals which correspond to the four SEGMAG machines indicate whether or not each is available for inclusion in the drive system.

In the active mode, the parameter HOLD is true which places the switch and circuit breaker commands under the dictates of the upper level supervisor. Thereby, the lower level supervisor temporarily looses track of the configuration. Upon reverting back to the passive mode, the parameter C_{old} reset provides the information as to which configuration the drive system is in.

Each of the nine parameters, S1OPEN...CB4OPEN, commands a switch or circuit breaker to open when true, otherwise the position is not altered. The upper level supervisor does not have the means of commanding an open switch or circuit breaker to close since this capability is not needed in order to fulfill its tasks.

Table 20 lists the upper level supervisor inputs to the dynamic control. The logical parameters HOLD1 and HOLD2 which apply to sides 1 and 2 respectively indicate if the upper level is in the passive or active mode.

The four field commands are only used as input to the exciter controls when the upper level is in the active mode.

Table 21 lists the upper level supervisor inputs to the test stand controls. The two emergency parameters, $EMER_{g1}$ and $EMER_{g2}$, are normally logical 0. When a fault or emergency cycle is initiated, the emergency signals

are changed to logical 1 and the result is to be a rapid shut down of the prime movers.

The two permissive parameters, $PERM_{g1}$ and $PERM_{g2}$, inform the prime mover controls if a generator may be driven (logical 1) or not (logical 0). If while a generator is being driven its permissive signal is changed to logical 0, an orderly shutdown of the prime mover is to result (as opposed to a rapid shut down).

Table 22 lists the four permissives from the test stand controls. They provide the upper level supervisor with the information of whether or not a prime mover is prepared to drive a generator and a load device is prepared to absorb power from a motor.

5.3 Block Diagram

This section discusses the roll that the various blocks in Figure 28 play and the interconnections between them. A detailed description of the internal functioning of each block is given in the next section.

When activated by the $START_{con}$ signal, the START/STOP block starts up the system primarily by initiating a restart cycle. Pushing the $STOP_{con}$ button shuts the system down in an orderly fashion by making all of the machine permissives false (logical 0). The START/STOP logic also generates a signal which provides the information of whether or not the drive system is operating in the split plant mode.

The PERM block generates a permissive signal for each SEGMAG generator and motor. In order for a permissive to be true, a number of conditions must be met, e.g. lube oil sufficient for operation, exciter energized, etc.

The AVAIL block uses the permissives for the SEGMAG machines and the permissives from the test stand controls in order to determine the availability of each generator and motor.

The STATUS block generates a four valued signal for each machine which provides the information of whether the machine is off, ready (prime mover not running), on standby (prime mover at idle), or on line. The status signals are used by the fault, emergency, and restart monitor logic.

The FAULT block may be activated either by a console push button or by its own drive system monitoring logic. When activated, the machine fields are rapidly deenergized and the emergency and restart cycles are set in motion.

When activated, the EMER block sends signals ($EMER_g$) to the prime mover controls which call for an emergency shut down of the prime movers. After a time delay (5 seconds), the restart cycle is initiated.

The RESTART block provides for an orderly deenergization of the drive system. At the end of the cycle, all of the switches and circuit breakers are open.

The HOLD block is activated whenever a fault, emergency, or restart cycle is set in motion. This block sends signals to the lower level supervisory and dynamic controls which has the effect of placing control under the upper level supervisor. The hold signals are also used as part of the permissive logic and reset logic.

The RESET block provides two signals, a reset signal and an updated value for C_{old} (i.e. C_{old} reset). In order to terminate a fault, emergency, or restart cycle, the reset signal must be made true. This can be done only when it is determined that the drive system is deenergized and when the operator pushes the start button on the console.

5.4 Logic

Figures 29 through 38 show the upper level logic. The figures correspond to one (or more) of the blocks shown in Figure 28.

The START/STOP logic is shown in Figure 29. When the control system is energized, the value of logical signal START must be 0, i.e. false. This causes STOP to be true which in turn makes the machine permissives false. When the starting button on the console is pushed, $START_{con}$ becomes true which initiates the restart cycle. The drive system should be deenergized already and RESET immediately becomes true. START then assumes a value of 1 and STOP becomes false. The restart cycle is terminated and the system control passes to the lower level.

The drive system is considered to be in the split plant mode (SPLIT=true) only when all of the cross connect switches, S1, S2, and S3 are open.

NOTE: When the control system power is turned on, START has the value 0

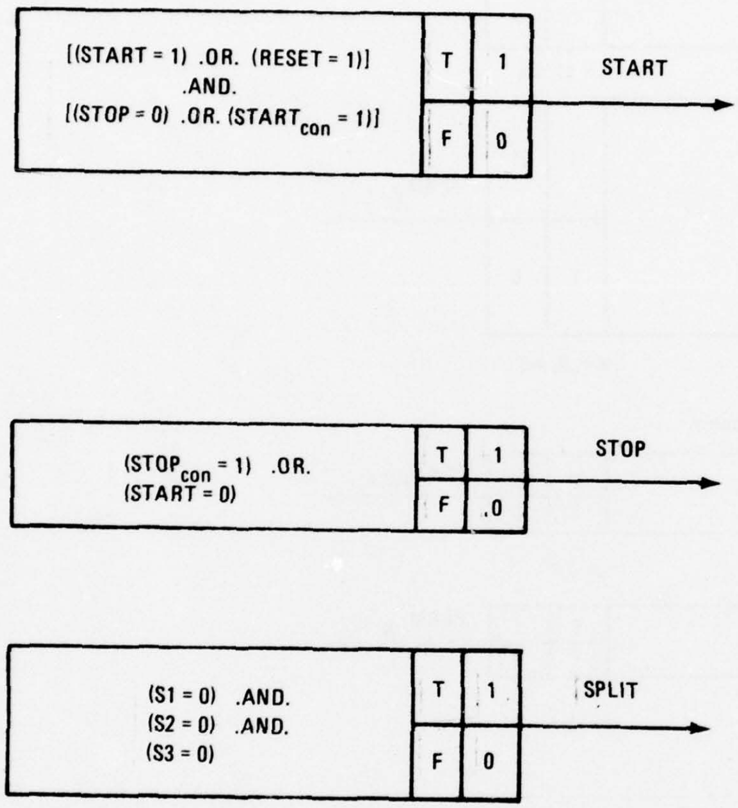


Figure 29 Start/Stop Logic

Condition			Output
(HOLD1 = 0) .AND. (STOP = 0) .AND. ($PERM_{conx}$ = 1) .AND. ($EXCIT_X$ = 1) .AND. ($CO2_X$ = 1) .AND. ($H2O_X$ = 1)	T	1	$PERM_X$
	F	0	

x = g1, m1

Condition			Output
(HOLD2) .AND. (STOP = 0) .AND. ($PERM_{conx}$ = 1) .AND. (OIL_X = 1) .AND. ($EXCIT_X$ = 1) .AND. ($CO2_X$ = 1) .AND. ($H2O_X$ = 1)	T	1	$PERM_X$
	F	0	

x = g2, m2

a) Originated at the SEGMAG control

Condition			Output
Prime Mover-X capable of Driving Generator-X	T	1	$PERM_{PMX}$
	F	0	

x = 1, 2

Condition			Output
Load-x Capable of Absorbing Power From Motor-X	T	1	$PERM_{LX}$
	F	0	

x = 1, 2

b) *Originated at the Test Stand*

Figure 30 Permissive Logic

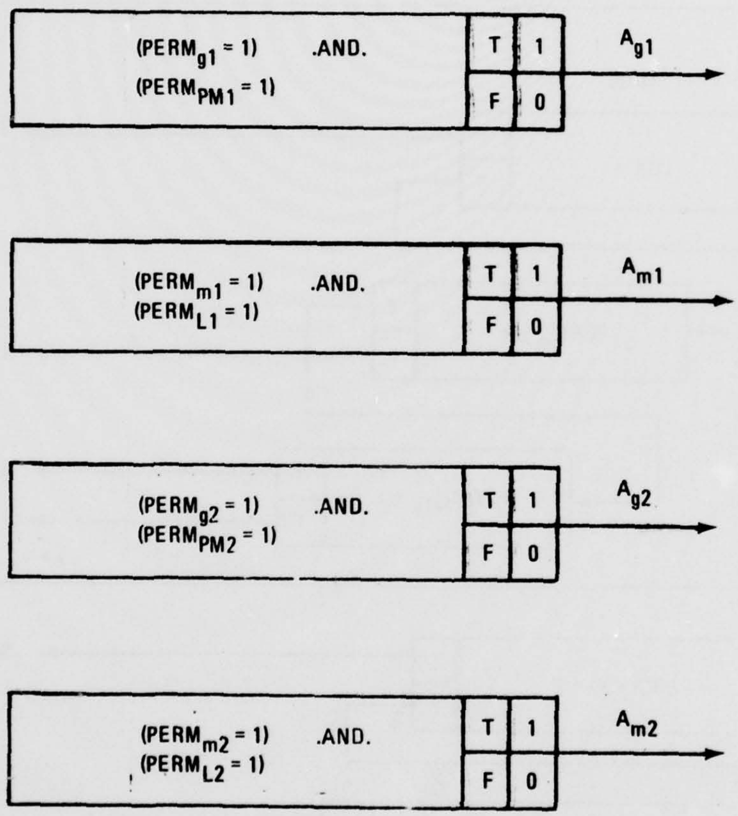


Figure 31 Availability Logic

DESCRIPTION

value of STATUS	status of SEGMAG machine	operating in the system?	SEGMAG permissive	test stand permissive
0	off	no	0	0 or 1
1	ready	no	1	0
2	standby	no	1	1
3	on line	yes	0 or 1	0 or 1

LOGIC

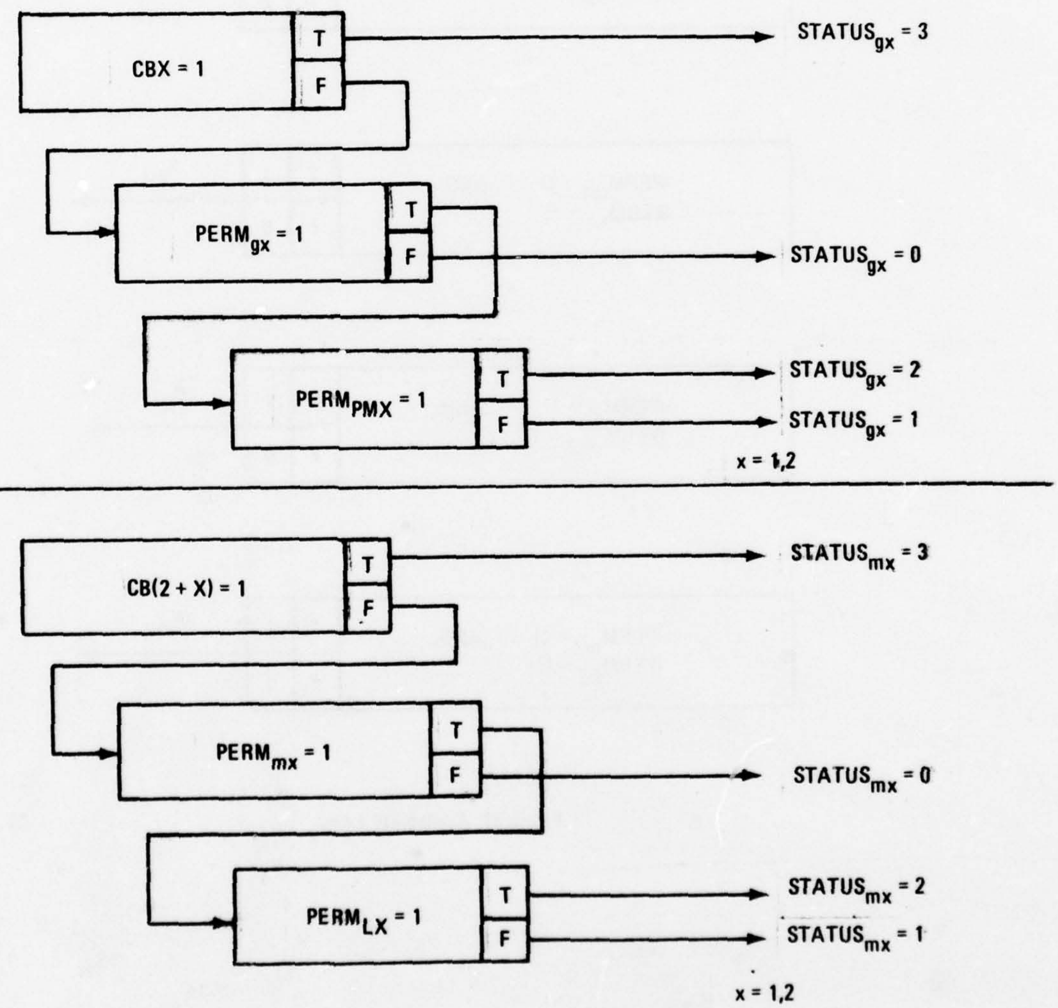


Figure 32 Status Logic

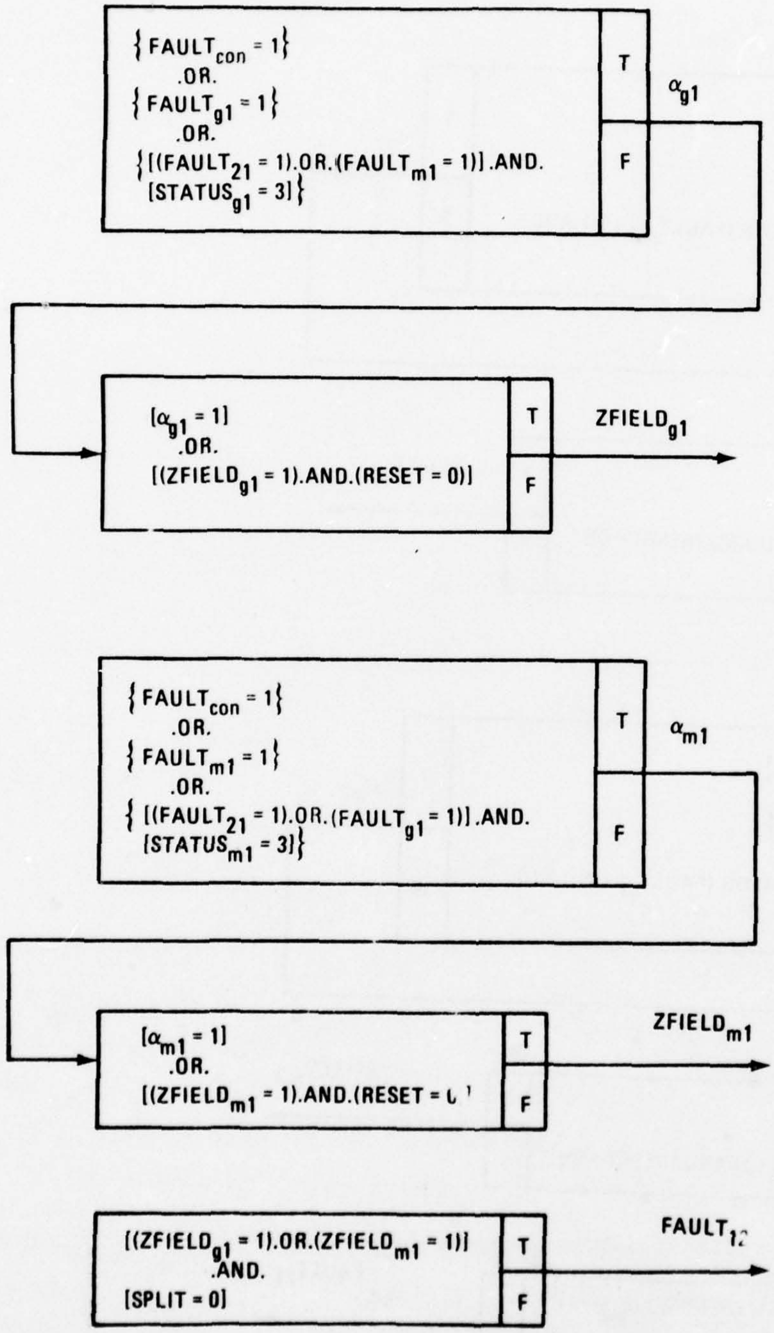


Figure 33a Fault Logic (Side 1)

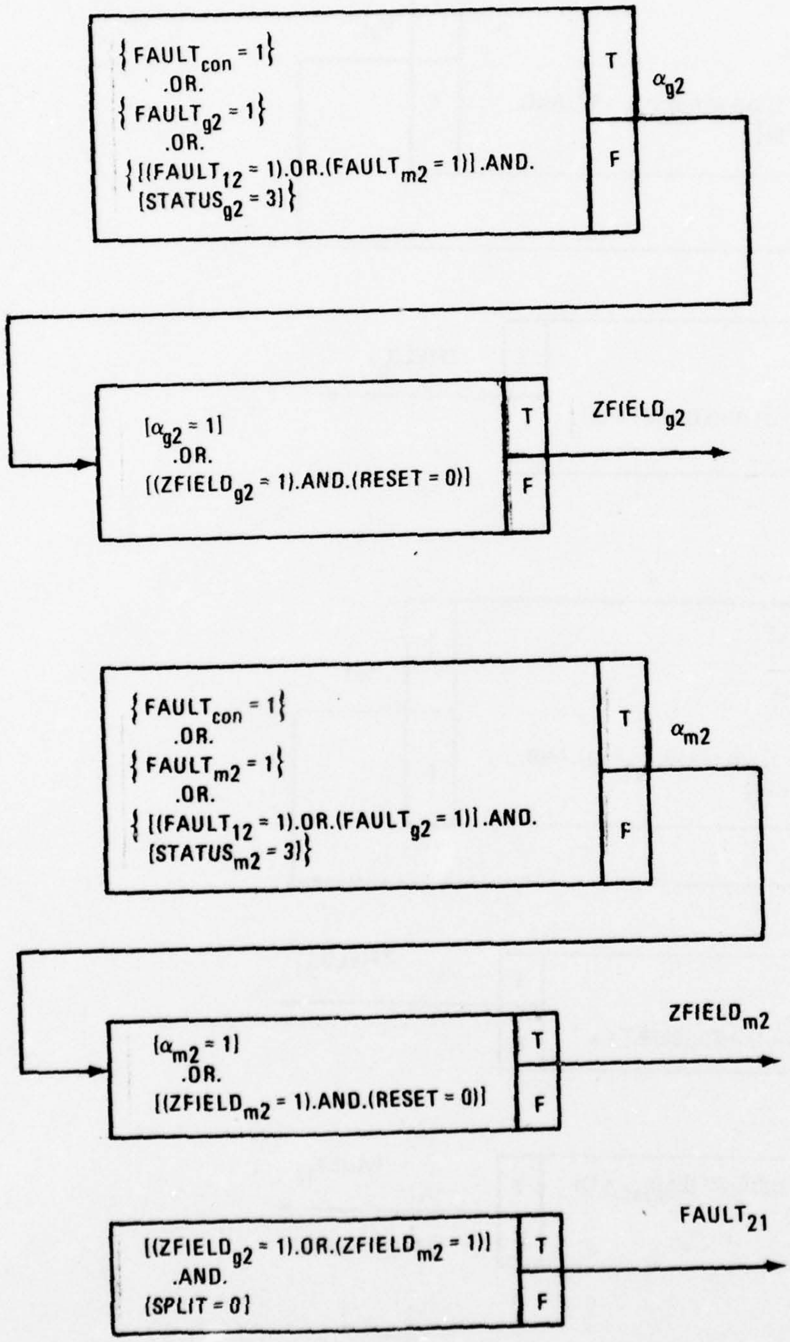


Figure 33b Fault Logic (Side 2)

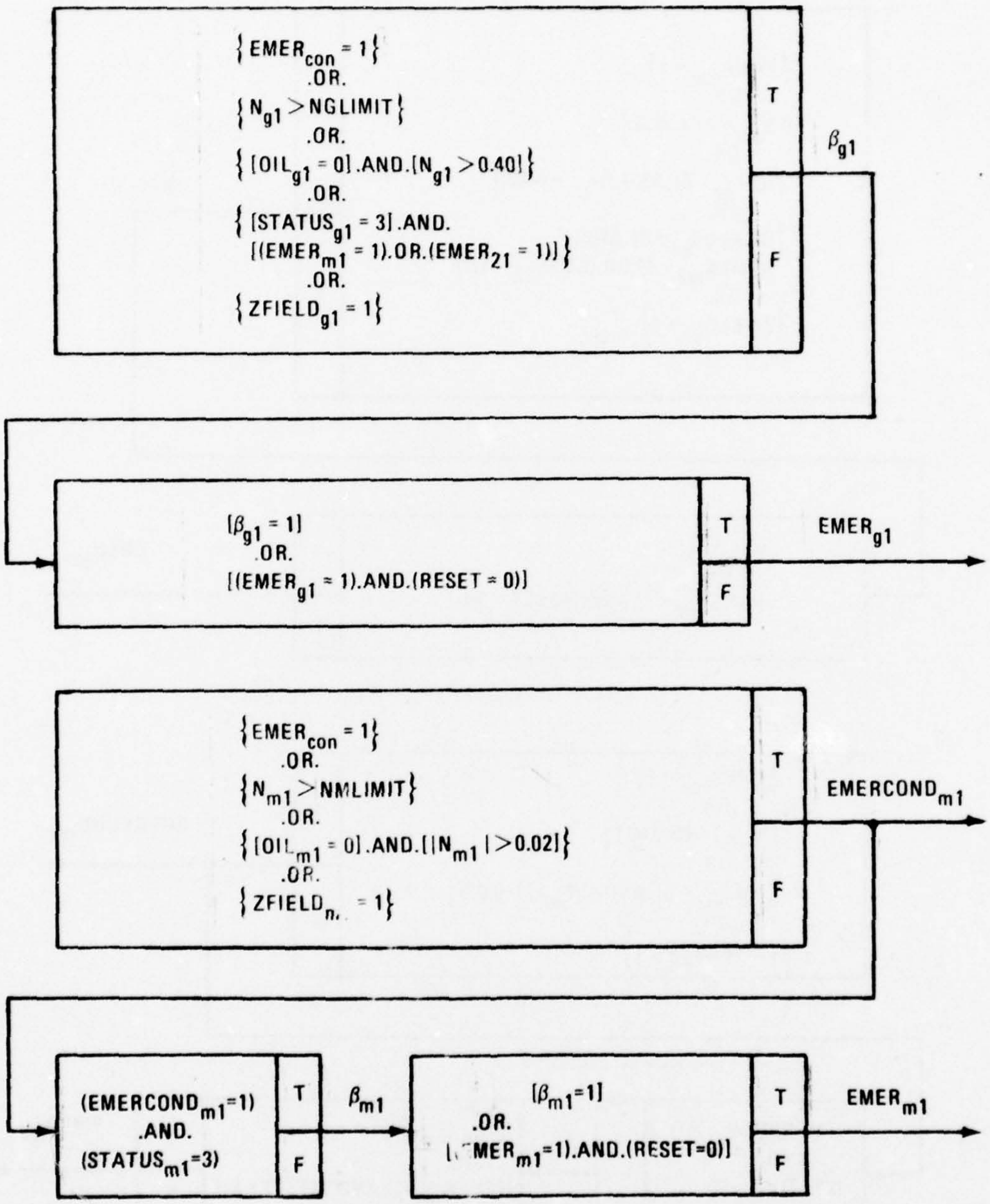


Figure 34a Emergency Logic (Side 1)

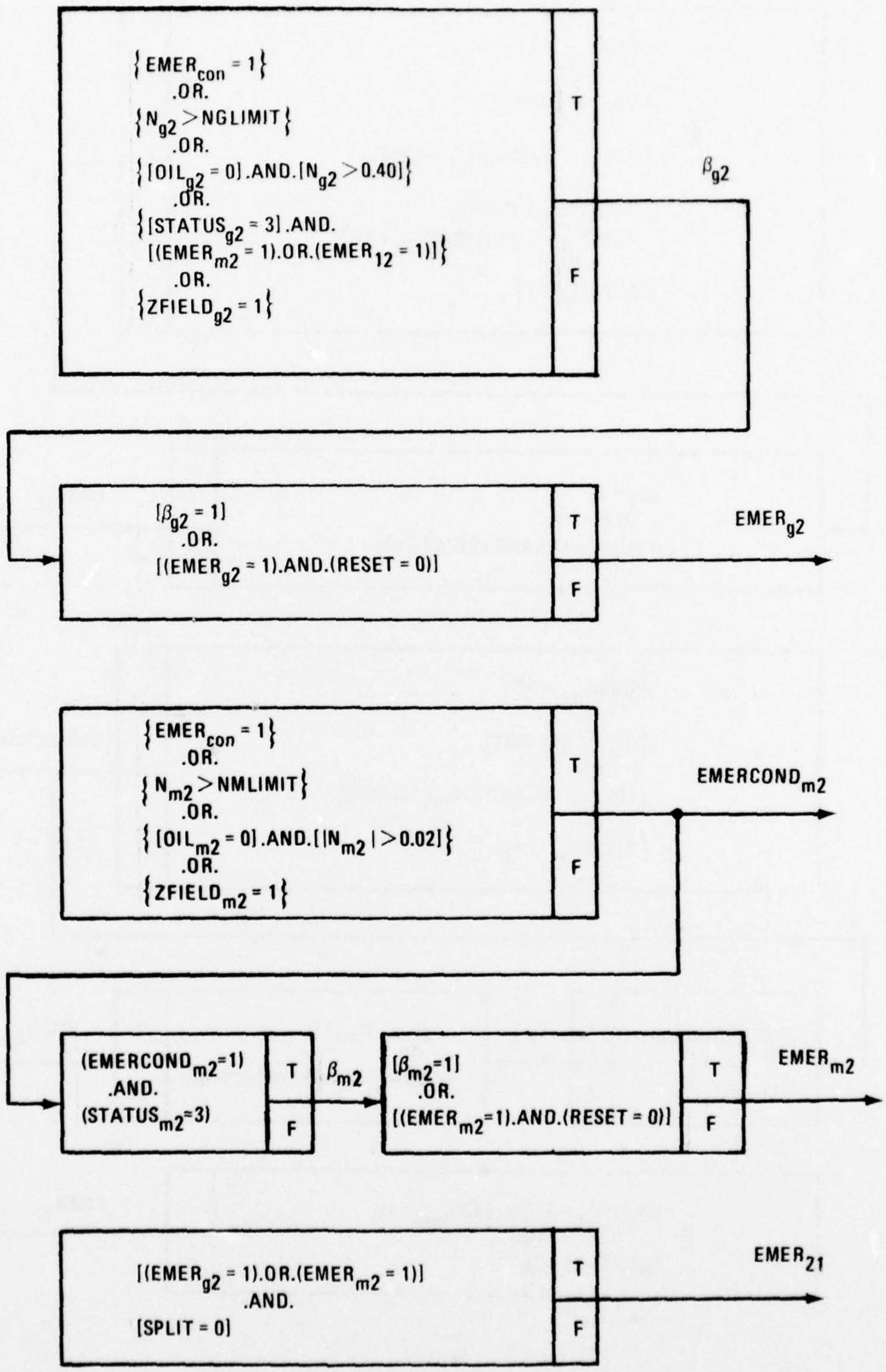


Figure 34b Emergency Logic (Side 2)

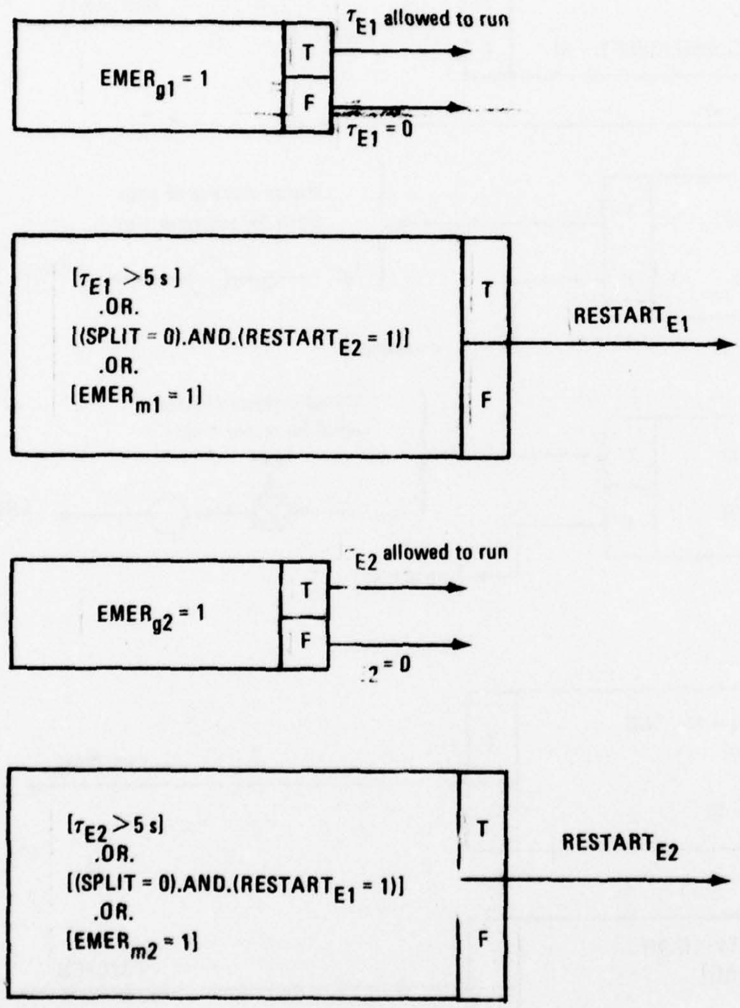


Figure 34c Emergency Logic (Sides 1 and 2)

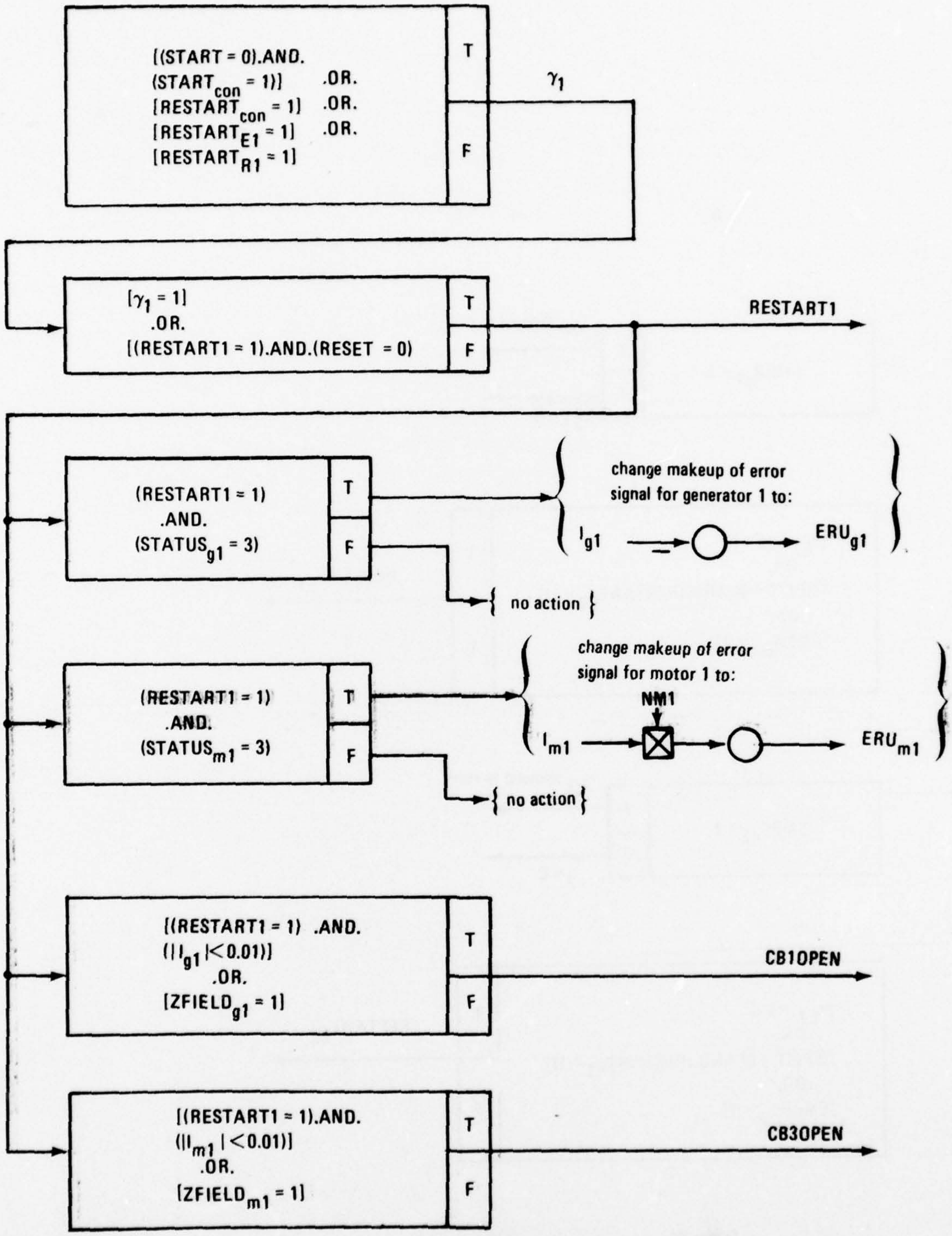


Figure 35a Restart Logic (Side 1)

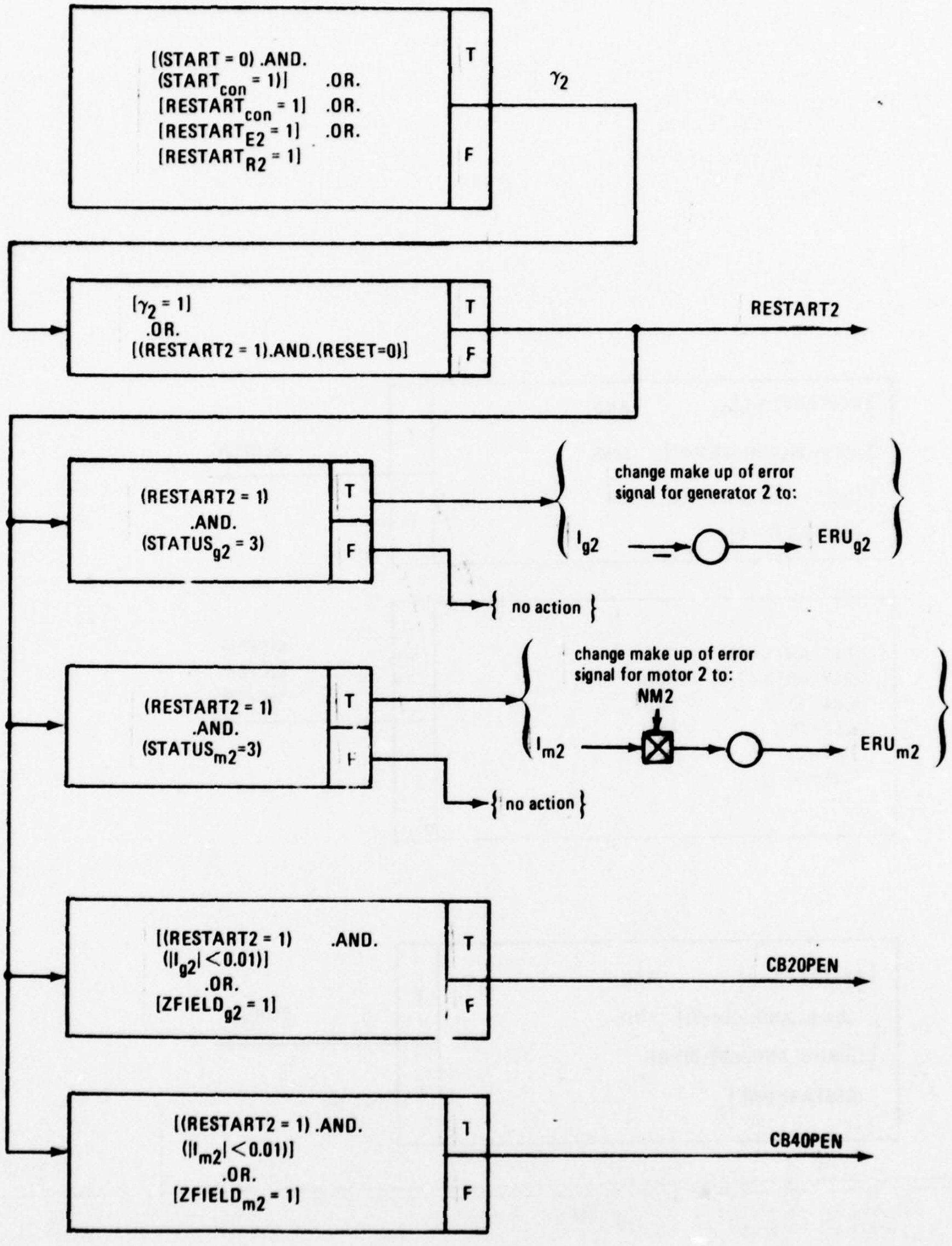


Figure 35b Restart Logic (Side 2)

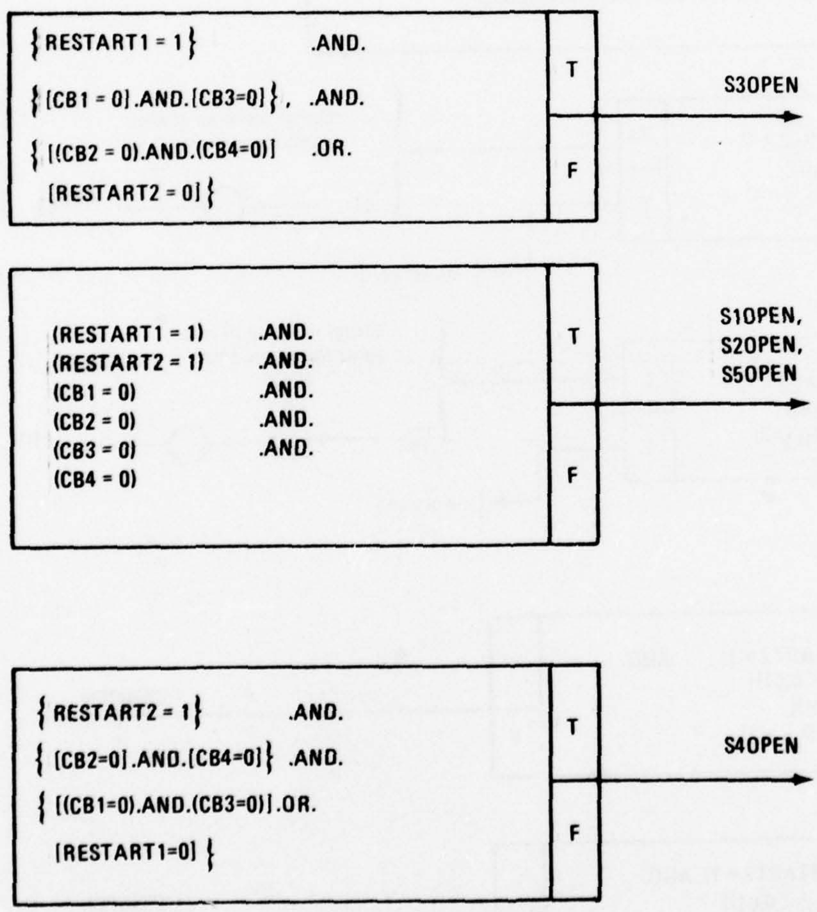


Figure 35c Restart Logic (Sides 1 and 2)

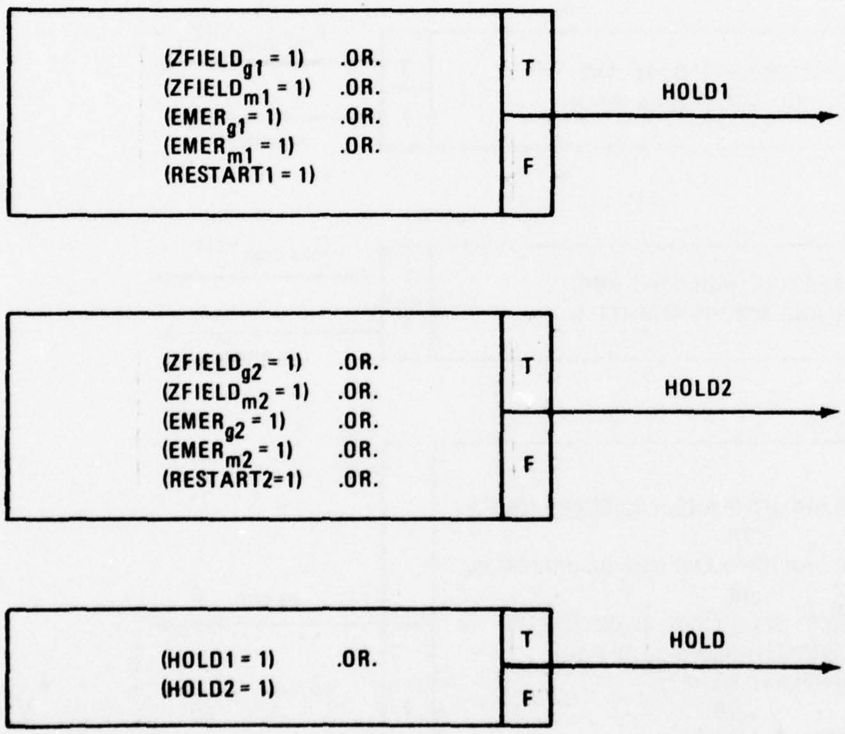


Figure 36 Hold Logic

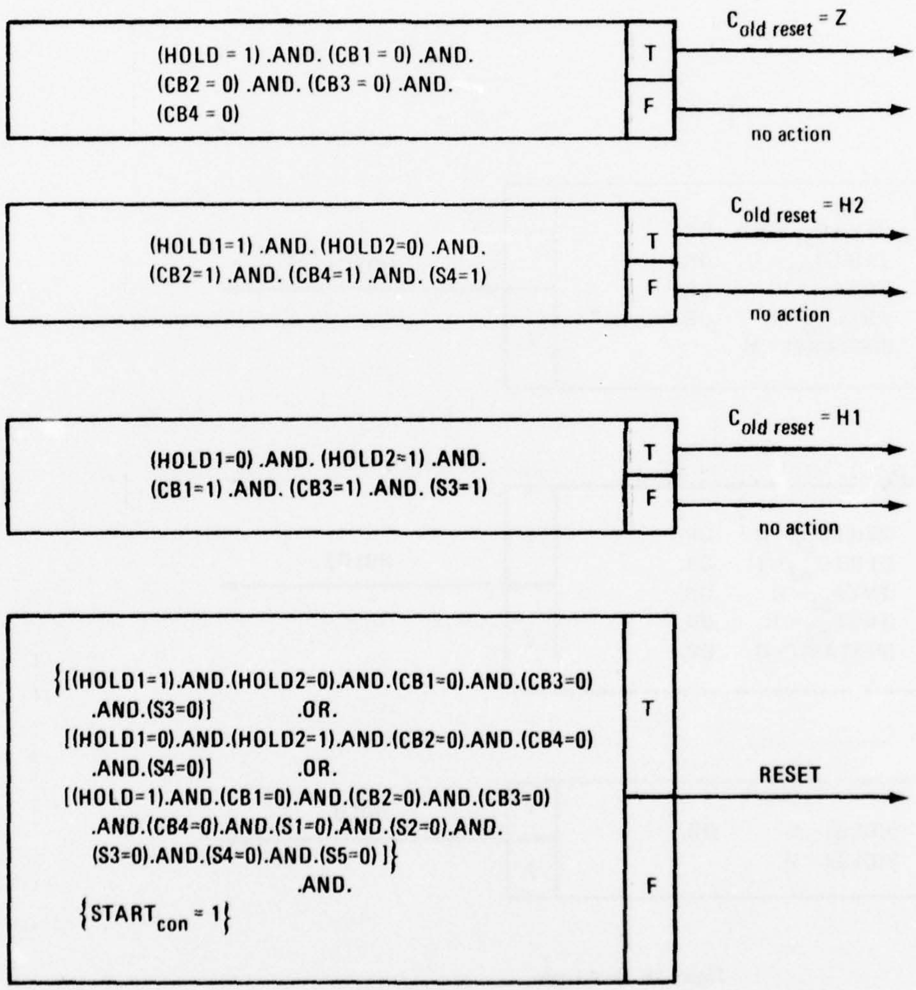


Figure 37 Reset Logic

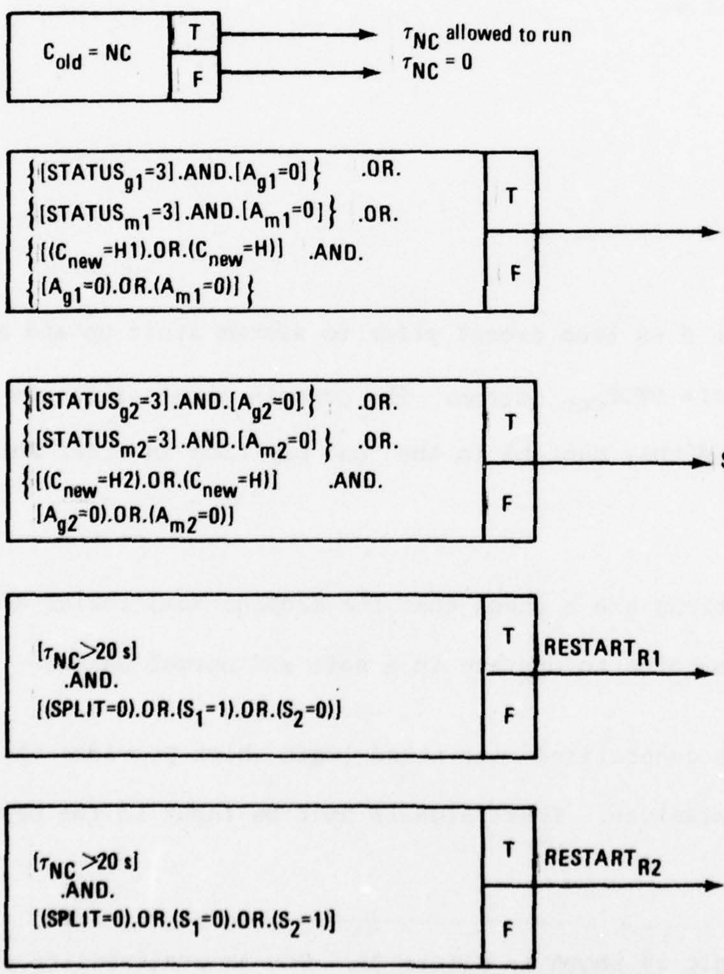


Figure 38 Restart Monitor Logic

Figure 30a shows the permissive logic. In order for a permissive signal to be true, a number of conditions must be met.

During a fault, emergency, or restart cycle, the hold signal for an effected side is true. For instance, if HOLD1 becomes true, the permissive for generator 1 becomes false which signals the test stand to shut down prime mover 1. The permissive for motor 1 would also become false which would disallow including this machine in the drive system.

The condition *STOP = 0 is true except prior* to system start up and after the operator has pushed the $STOP_{con}$ button. The console permissives are under operator control and they must be in the "on" position in order for PERM to be true.

The last four conditions are a check that the machine auxiliaries are in a state that allows the machine to operate in a safe and normal manner.

Figure 30b shows the generalized test stand logic which provides the prime mover and load permissives. These signals must be input to the upper level.

The availability logic is shown in Figure 31. For an availability signal to be true, the machine permissive and corresponding prime mover or load permissive must both be true.

Figure 32 shows the status logic required to generate the four status signals, one for each SEGMAG machine. As opposed to the other upper level signals, these are four value instead of two value parameters.

The circuit breaker positions are used to determine if a machine is operating in the drive system, i.e. on line. If not on line, the permissive signals are used to determine if a machine is off, ready, or on standby.

The fault logic for side 1 is shown in Figure 33a. Normally, all of the logic signals shown are false with the exception of SPLIT which may have a value of either 0 or 1 depending upon whether the drive system is in the split plant mode or not.

The parameter α_{g1} becomes true whenever one or more of the following sets of conditions become true:

1. The console fault command is given by the operator.

2. A fault at generator-1 is detected due to either of the following:

   a. The absolute value of the measured generator current, $|I_{g1}|$, exceeds a preset value (e.g. 200 percent of rated current).

   b. Circuit breaker-1 trips instantaneously.

3. The generator is operating in the system ($STATUS_{g3} = 3$) and either of the following holds true:

   a. A fault is detected on side 2 and the drive system is not in the split plant mode ($FAULT_{21} = 1$).

b. A fault at motor-1 is detected ($FAULT_{m1} = 1$).

When α_{g1} becomes true, $ZFIELD_{g1}$ also becomes true which signals a rapid deenergization of generator field-1. Also, through the restart logic, circuit breaker-1 is commanded to open.

Even if α_{g1} is only momentarily true, $ZFIELD_{g1}$ remains true until the reset signal is activated (RESET = 1) which cannot occur until the system has been deenergized, i.e. the circuit breakers and switches have been opened.

In general, α_{g1} should be false by the time the reset signal is given. However, if for some reason a fault condition is still detected, $ZFIELD_{g1}$ would remain true until the condition changed.

The fault logic for motor-1 has the same structure as that for generator-1. The effect of $ZFIELD_{m1}$ becoming true is the rapid deenergization of motor field-1 and the opening of circuit breaker-3.

The logic signal $FAULT_{12}$ is used in the fault logic for side 2 and it corresponds to $FAULT_{21}$. If a fault is detected on side 1 and the two sides are connected (SPLIT = 0), $FAULT_{12}$ becomes true. This in turn results in ZFIELD becoming true for those machines on side 2 which are connected in the drive system.

The fault logic for side 2 is shown in Figure 33b and it is a mirror image of that for side 1.

Figures 34a and part of 34c show the emergency logic for side 1. The logic parameters β and EMER are similar to the fault logic parameters, α and ZFIELD.

The parameter β_{g1} is true whenever one or more of the following sets of conditions are true:

1. The console emergency command is given by the operator.

2. The generator-1 speed exceeds a preset value (e.g. 115 percent of rated speed)

3. The lube oil system for generator-1 is not operating in a manner to allow safe genertor operation and the generator speed is in excess of 0.4 p.u. Note that the generator normally operates between 0.50 p.u. (no load) and 1.0 p.u. (full load).

4. Generator-1 is operating in the system (STATUSg1 = 3) and either of the following holds true:

   a. An emergency condition for motor-1 is detected (EMERm1 = 1).

   b. An emergency condition is detected on side 2 and the drive system is not in the split plant mode (EMER21 = 1).

5. A fault on generator-1 is detected ($ZFIELD_{g1} = 1$).

When $\beta g1$ becomes true, EMERg1 also becomes true which signals the test stand that prime mover-1 is to be shut down rapidly. Even if β_{g1} is only momentarily true, EMERg1 remains true until the reset signal is activated.

The emergency logic for motor-1 is structured a little differently than that for generator-1. The reason for this is that the load is considered to be strictly a function of rotational speed and cannot be commanded to shutdown

like a prime mover. In a shipboard application, the load (i.e. propeller) is a function of the ship's speed and shaft rotational speed, and therefore, the most that the control system could do under emergency conditions would be to stop the motor from being driven.

The motor emergency condition parameter, $EMERCOND_{m1}$, is true whenever one or more of the following sets of conditions are true:

1. The console emergency command is given by the operator.

2. The motor-1 speed exceeds a preset value (e.g. 110 percent of rated speed).

3. The lube oil system for motor-1 is not operating in a manner to allow safe motor operation and the absolute value of the motor speed is in excess of 0.02 p.u. Note that in a shipboard application, this condition could persist for a lengthy period if there were a malfunction in the lube oil system for one motor and it were necessary to continue driving the ship with the other side.

4. A fault on motor-1 is detected ($ZFIELD_{m1} = 1$).

In order for β_{m1} to be true, both an emergency condition must be detected ($EMERCOND_{m1} = 1$) and the motor must be connected in the electrical power system ($STATUS_{m1} = 3$). When β_{m1} becomes true, $EMER_{m1}$ also becomes true and the prime mover/generators which are driving the motor are commanded to shutdown rapidly.

After the motor has been disconnected from the drive system ($STATUS_{m1}$ = 3), the start command from the console will return control to the lower level. However, it is up to the operator to assess the cause of the emergency condition and take appropriate action. For instance, if on a shipboard application a screw is dropped and the motor overspeeds the operator should change the console permissive switch for the motor to logical 0. Otherwise the whole emergency cycle could be needlessly repeated. If on the other hand, a malfunction in the lube system were the case, then the upper level permissive logic would not allow the motor to be included in the drive system. It would then be up to the operator to decide whether or not to continue driving the ship with the other screw.

The logic signal $EMER_{12}$ is used in the emergency logic for side 2 and it corresponds to $EMER_{21}$. If an emergency condition is detected on side 1 and the two sides are connected (SPLIT = 0), $EMER_{12}$ becomes true. This in turn results in $EMER_{g2}$ becoming true if generator-2 is connected in the drive system.

Figure 34b shows the emergency logic for side 2 which corresponds to the side 1 logic shown in Figure 34a.

Figure 34c shows the emergency logic which activates the restart cycle. For side 1, if $EMER_{g1}$ becomes true, the clock parameter, τ_{E1}, starts counting from 0. The restart cycle for side 1 is initiated whenever one or more of the following conditions are true:

1. The clock parameter, τ_{E1}, exceeds 5 seconds.

2. The motor emergency parameter, $EMER_{m1}$, is true.

3. A restart is initiated on side 2 ($RESTART_{E2}$ = 1) and the two sides are connected (SPLIT = 0).

The rational for the time of initiating the restart cycle is as follows. If an emergency arises on the generator only, it seems prudent to keep it loaded for some period (e.g. 5 seconds) in order to reduce the speed more quickly than if it were unloaded. The restart cycle results in the power transfer between the SEGMAG machines going to zero fairly rapidly. This cycle should not be delayed too long for, at least in a shipboard application, the motor could eventually start driving the generator.

If an emergency condition arises on the motor, the restart cycle is immediately initiated which will more rapidly decrease the power input to the motor than just giving the command to shutdown the prime mover(s) rapidly. This power differential is stored in the generator rotating mass(es).

The initiation of the restart cycle for side 2 has the same logic structure as that for side 1.

Figures 35a and part of 35c show the restart logic for side 1. The logic parameters γ and RESTART are similar to the emergency parameters β and EMER and the fault parameters α and ZFIELD.

The parameter Υ_1 is true whenever one or more of the following set of conditions are true:

1. The starting cycle is initiated by the operator (START = 0 and $START_{con}$ = 1). Note that once the control system is started, START remains true until the console stop command is given.

2. The restart cycle is initiated by the operator ($RESTART_{con}$ = 1).

3. The emergency cycle initiates the restart cycle ($RESTART_{E1}$ = 1).

4. The restart monitor initiates the restart cycle ($RESTART_{R1}$ = 1).

When Υ_1 becomes true, $RESTART_1$ also becomes true. The immediate result is a change in make up of the error signals for generator 1 and motor 1 if they are operating in the drive system (STATUS = 3). The changes are such that the fields strive to produce zero armature current.

In the case of the generator, the error signal, ERU_{g1}, is the negative of the armature current. If the current is positive, the error signal is negative and the field current is reduced.

For the motor, the direction of rotation must be taken into account which is the purpose of multiplying the motor armature current signal by NM1 which has a value of +1 in the positive rotational direction and -1 in the opposite direction. If NM1 and the armature current are of the same sign, the error signal is positive which causes the motor field control, MF_1, to try and increase the motor field current, I_{fm1}.

When the absolute value of the armature current is less than 45A, the circuit breakers are commanded to open (CB1OPEN = 1 and CB3OPEN = 1). However, if a fault cycle were initiated which affected side 1, the circuit breakers would immediately be commanded open due to the change in ZFIELD from logical 0 to logical 1.

The corresponding logic for side 2 is shown in Figure 35b.

The last part of the restart logic (Figure 35c) is concerned with the opening of the switches. The logic is set up such that the appropriate circuit breakers are shown to be open before the command(s) to open the switch(es) may be given.

The first logic block gives the command to open switch 3 under two conditions only. If the restart affected side 1 only (i.e. split plant mode) the circuit breaker position signals on side 1 must be logical 0, i.e. the signals indicate that the circuit breakers CB1 and CB3 are open. If the restart affected both sides, it must be indicated that all four circuit breakers are open.

The second logic block gives the commands to open all of the cross connect switches: S1, S2, and S5. These commands are only given if the restart cycle affects both sides and all circuit breakers are indicated to be in the open position.

The last logic block gives the command to open switch 4. This block is a mirror image of the first block shown in the figure.

The hold logic is shown in Figure 36. The three hold signals, one for each side plus one for the whole system, are normal false (logical 0).

Whenever a fault, emergency, or restart cycle is initiated on side 1, HOLD1 becomes true. It should be noted that any of the signals used to determine HOLD1 which become true, will remain true until the reset command is given.

The logic for HOLD2 is the same as for side 1 except that the signals monitored are on side 2.

The HOLD signal is true whenever either HOLD1 or HOLD2 or both are true.

The hold signals are used to allow the upper level to take over control of parameters normally under the direction of the lower level.

Figure 37 shows the reset logic which generates two parameters: $C_{old\ reset}$ and RESET.

Before returning control to the lower level after a fault, emergency, or restart cycle, an updated value for C_{old}, $C_{old\ reset}$, must be supplied. This is because the lower level logic keeps correct track of the system configuration only if its control is continuous. As shown in the figure, $C_{old\ reset}$ may have any of three values: Z, H2, or H1.

In order for RESET to be true, three basic conditions must be met:

1. A fault, emergency, or restart cycle has been initiated. This is true when some or all of the hold parameters are true.

2. The cycle is completed which is determined by monitoring the appropriate circuit breaker and switch position signals.

3. The operator gives the start command.

Usually, by the time the first and second conditions listed above are true, all of the α's, β's, and γ's will be false. When the operator gives the start command, RESTART becomes true which then allows the ZFIELD, EMER, and RESTART parameters which are true to become false. When these conditions have been met, the hold signals become false and control is returned to the lower level. Simultaneously, RESET is changed from logical 1 to logical 0.

The restart monitor logic is shown in Figure 38. It activates a restart cycle whenever the time of transition from one configuration to another exceeds a limiting value (e.g. 20 seconds).

When a transition is initiated, C_{old} is changed to NC and the clock parameter, τ_{NC}, starts counting from 0. Upon completing a transition, C_{old} is changed to a value which reflects the new configuration and the clock parameter is reset and held at 0.

The second and third logic blocks use the status, availability, and C_{new} signals to determine if one or both sides are affected by the transition.

If the clock parameter exceeds 20 seconds, one or both of the restart monitor signals become true and a restart cycle is initiated.

8

APPENDIX NO. 8

3000 HORSEPOWER, 4 POLE GENERATOR DRAWINGS

GENERAL ASSEMBLY

ROTOR

		REV
Final Machining Assy.	1435E28	1
Conductor Bar	1696B48	1
Conductor	6427A25	2
Riser Brazing Sub Assy.	1696B81	1
Riser	2616C90	1
Conductor Cooling Tube Support Ring	2614C73	1
Chrome Plate & Prelim. Balance	8524D65	1
Commutator Bar & Support Ring Assy.	8521D44	1
Sprt. Ring & Comm. Bar Flame Spray Det.	2614C83	1
Comm. Bar, Comm. Sprt., Ring & Punch Ret. Key	8521D26	1
Insul. Ring, Bal. Block, Adapter & Fixture Dets.	2616C61	1
Punching, Stacking & Machining	1432E53	1
Ret. Pl. Assy. & Flame Spray	1696B46	1
Coolant Ring Braze Assy.	2616C76	1
Commutator Coolant Fitting	6426A48	1
Coolant Ring, Ftg., Cplg, Washer & Syphon Pipe Dets.	8521D22	1
Punching	8519D38	2
End Ring, Key, Pultrusion Key, & Shaft Key	8521D23	1
Forging Weld & Machining	1432E52	2
Drive End Forging Rough Machining	2618C31	2
Blank End Forging Rough Machining	8524D88	2
Shaft Forging	2614C59	4
Coolant Guide Assy.	8521D24	3
Coolant Baffle Tube	1691B96	2
Rotating Union	6425A42	1
Coupling Modification	1698B36	1

STATOR

		REV
Housing & Stator Assy.	1289J53	1
Brush Access Panel & Gasket	8521D91	1
Cooling Manifold Be. Rear	8522D74	1
Cooling Manifold De. Front	8522D75	1
Cooling Manifold Be. Front	8522D73	1
Cooling Manifold De. Rear	8522D76	1
Clamp Details	2614C91	1
Terminal Box	8525D31	1
Terminal Box	8525D30	1
Terminal Box Cover & Gasket Dets.	2618C76	1
Terminal Box Cover & Gasket Dets.	2618C77	1
Stuffing Tube Mtg. Plates - Term Box	2618C72	1
Shunt Det. - Term Box	2618C13	2
Details - Term Box	8525D62	1
Lam., Hsg. & Field Coil Assy.	8525D45	1
Field Coil	8520D33	3
Magnetic Shield (End Sect.) Field Coil	2615C55	1
Field Coil Sprt & Lamination Ret Rod Dets.	2614C72	1
Lamination & Hsg. Assy.	1432E54	1
End Connection to Brush Shunt	2615C01	1
End Connection	8521D54	1
End Connection	8521D57	1
End Connection	8521D56	1
End Connection	8521D58	1
End Connection	8521D55	1
Lamination Segment Assy.	8522D31	1
Lamination Segment	8519D37	2
Lamination End Plate Det.	8521D21	2
Return Conductor Wedge	1692B64	1
Return Conductor	1696B80	1
Return Conductor Bars	1693B30	1

		REV
Bearing Bore Machining	8522D50	1
End Bell Det.	639F500	1
Housing Weld Assy.	1435E23	2
Housing Shell (Center)	2614C85	1
Housing Shell (End)	2614C86	1
Sprt. Flg., Face Flg. & Ring Dets.	2618C98	1
Terminal Box Flange	2618C18	1
Field Coil Heater, Cndct Cool Tube, Wedge & Lifting Brkt.	8522D34	1
MISC. & SPECIAL INSTRUCTIONS		
Outline - Interface Dwg.	1435E29	1
5" × 5" Journal & Thrust Bearing	2618C69	1
Shunt Layout	8524D93	1
Torque Specifications	6435A48	1
Cleaning Procedure	1697B64	1
Mat'l Cleaning Procedure for Brazing	6440A40	1
Dielectric Test for Cndct. Bars	1698B66	1

AD-A060 782 WESTINGHOUSE RESEARCH AND DEVELOPMENT CENTER PITTSBU--ETC F/G 9/3
SEGMAG MACHINES FOR MARINE ELECTRICAL PROPULSION SYSTEMS. APPEN--ETC(U)
SEP 78 N00014-77-C-0307

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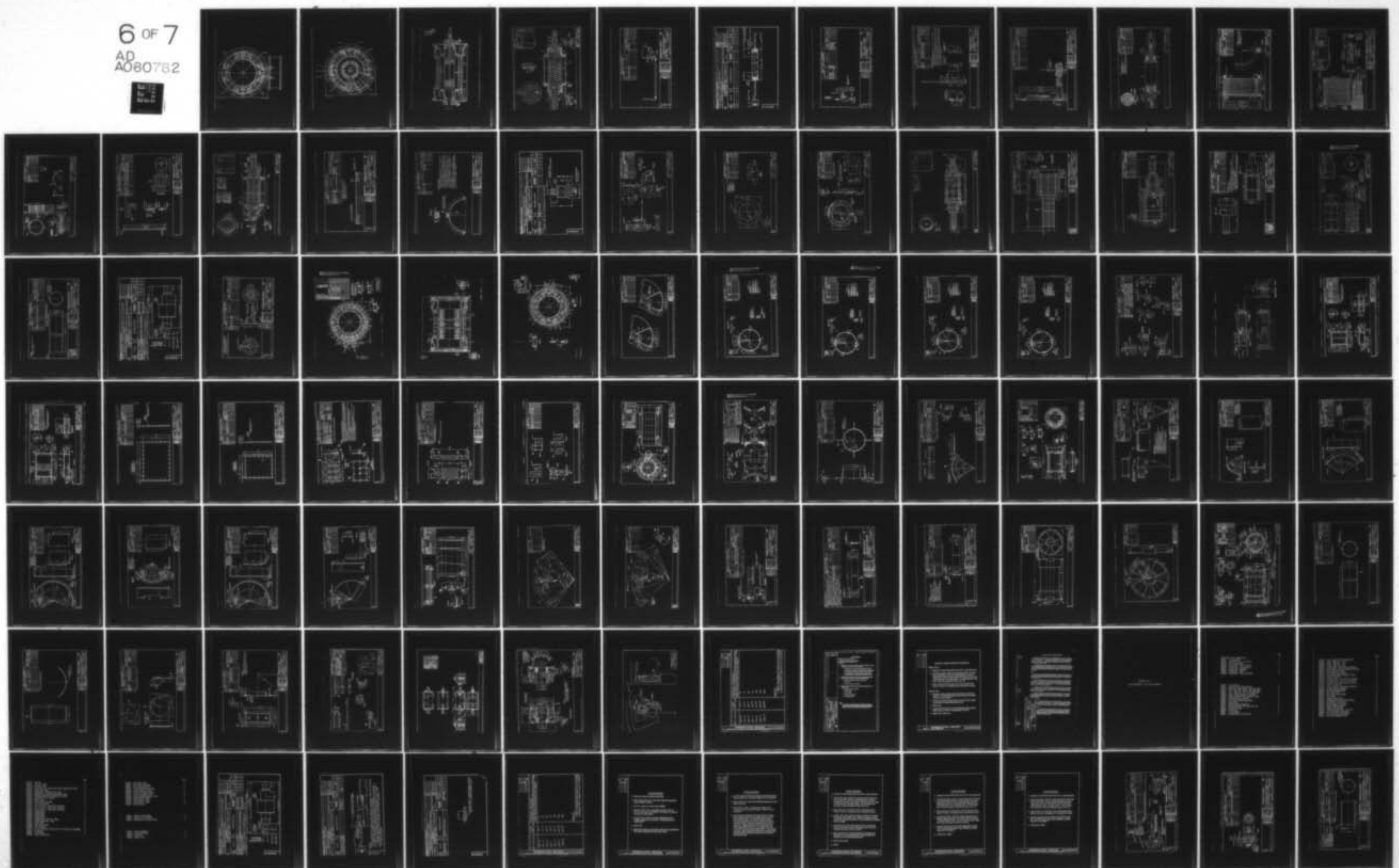
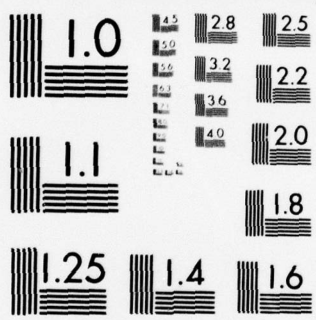
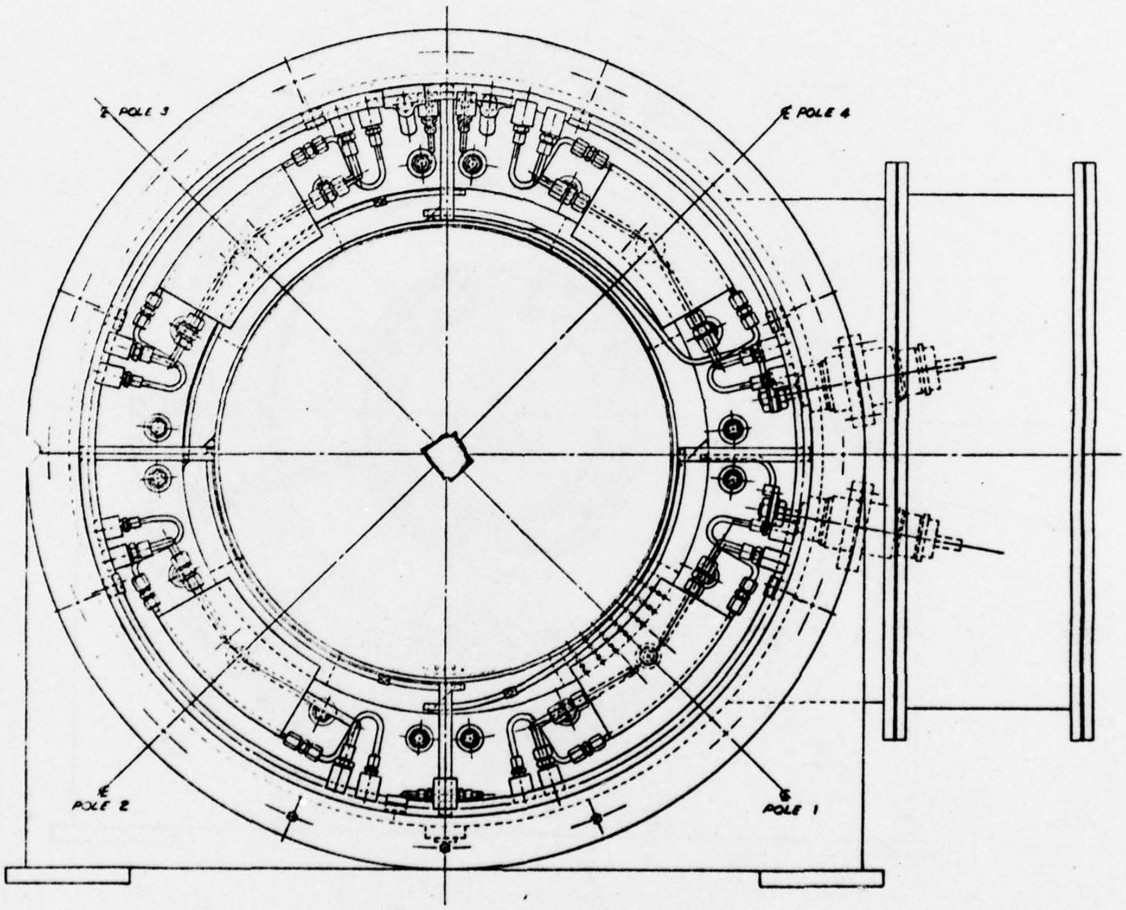
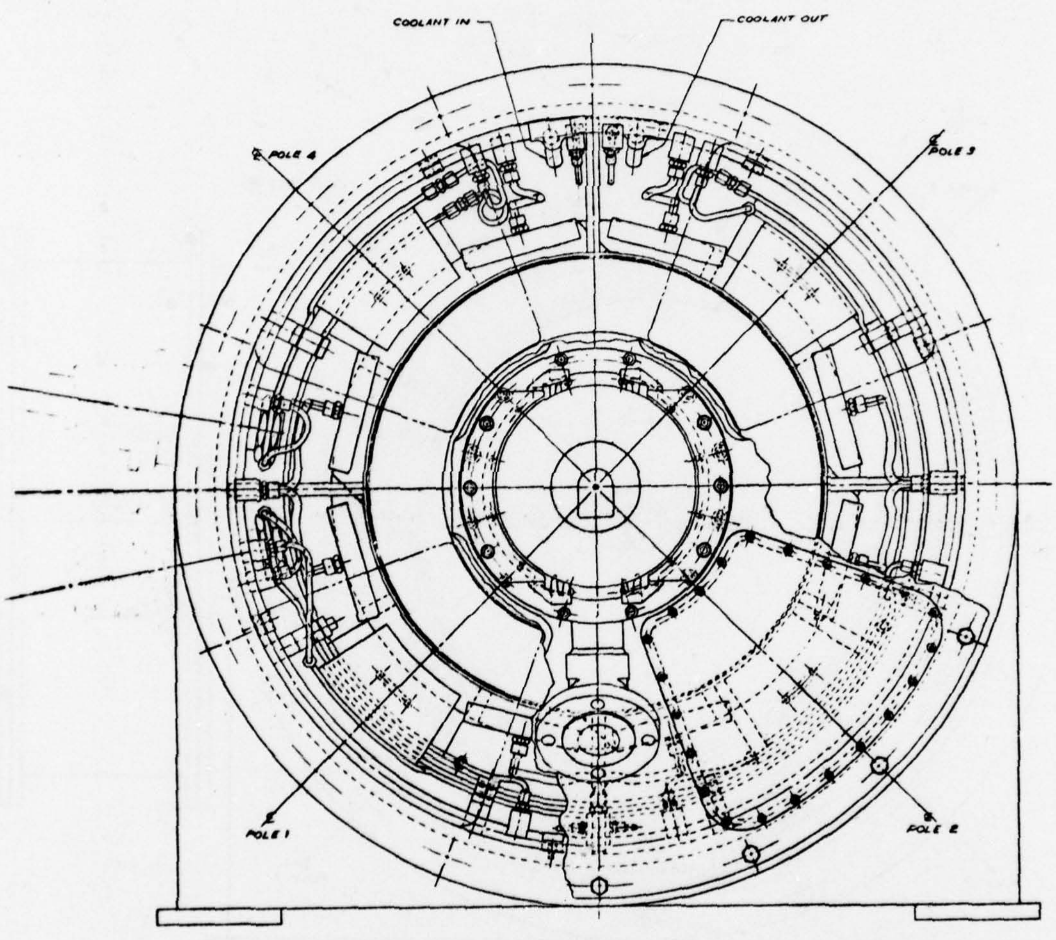




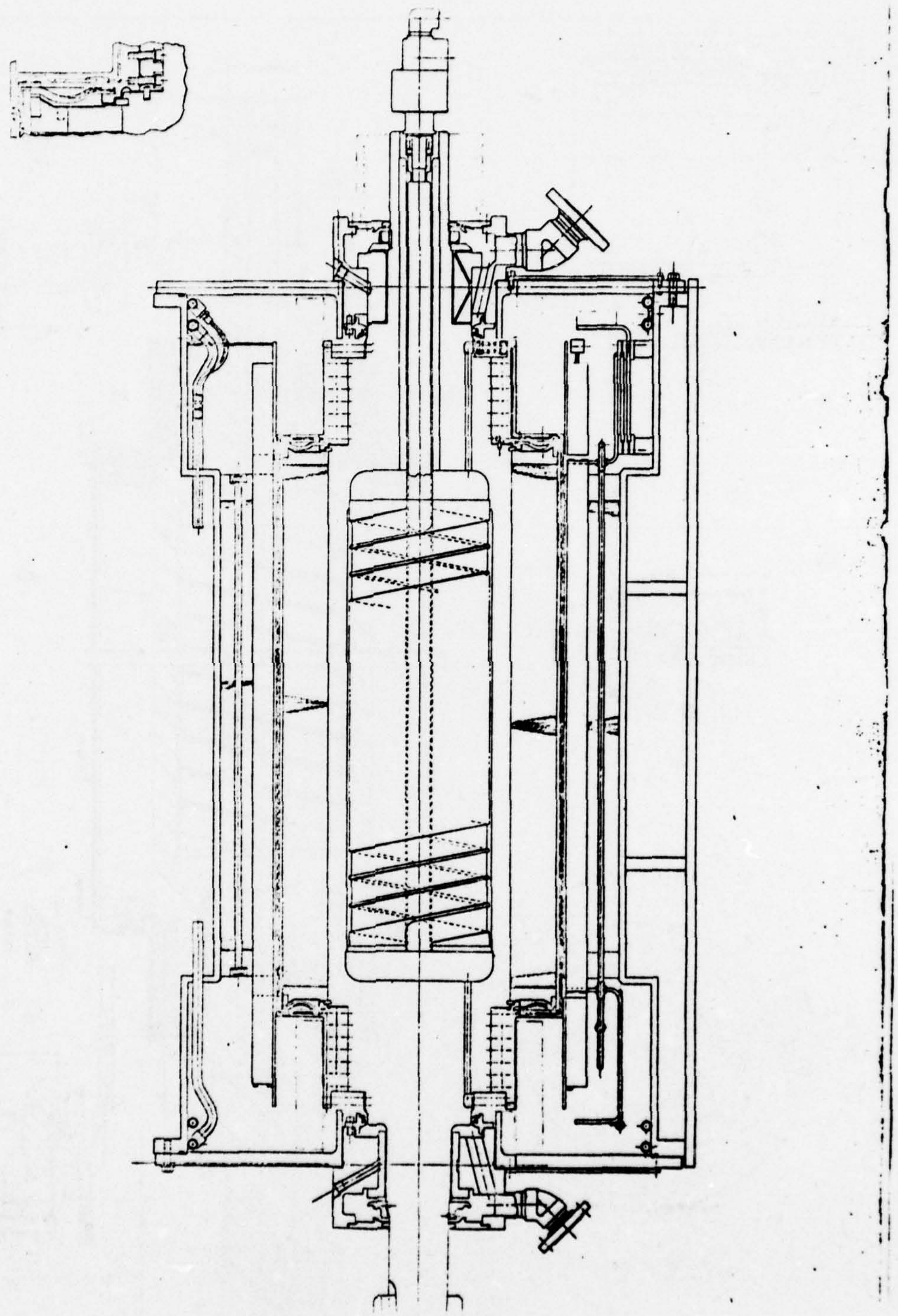
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

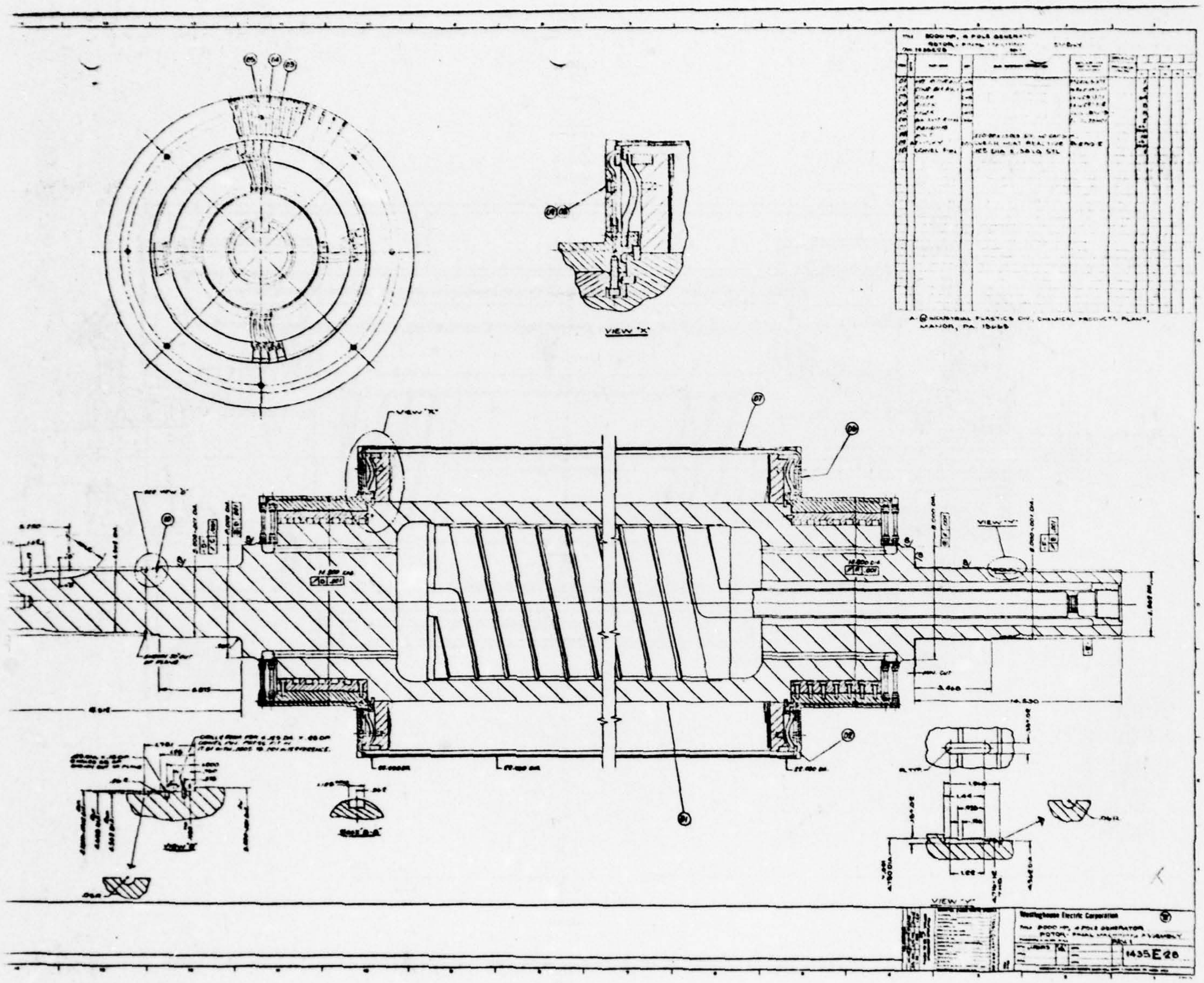


℄ POLE 3
℄ POLE 4
℄ POLE 2
℄ POLE 1



COOLANT IN
COOLANT OUT
℄ POLE 4
℄ POLE 3
℄ POLE 1
℄ POLE 2

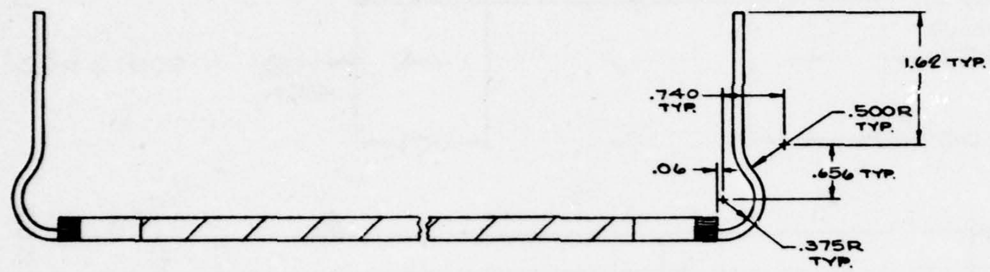




VIEW "X"
VIEW "Y"
Westinghouse Electric Corporation
1435E28

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - CONDUCTOR BAR
DWG 1696B48 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		CONDUCTOR	DWG		6427A25H01						



Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - CONDUCTOR BAR
REV. 1

DIMENSIONS IN INCHES—SCALE

DFTM H. Kozlowski 4-12-78

1696B48

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

CHANGE

Westinghouse Electric Corporation R&D CENTER, 1310 BEULAH RD., PITTSBURGH, PA. 15235 USA

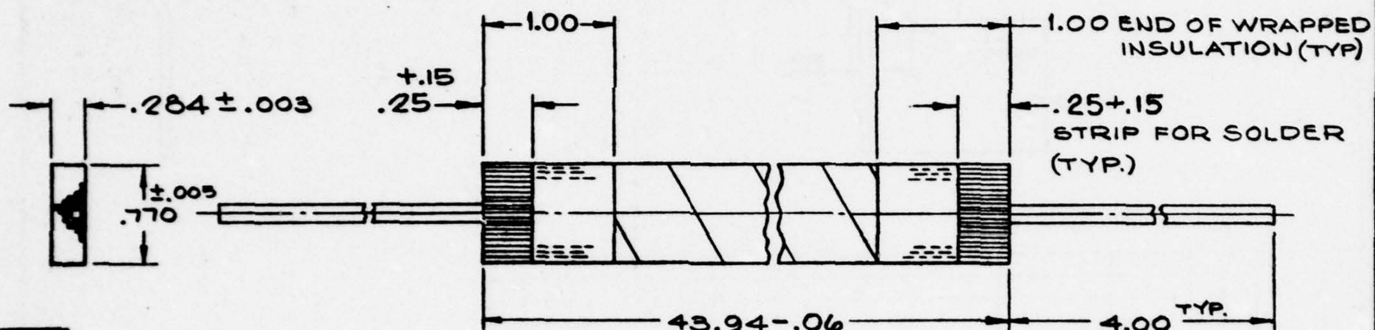
TITLE 3000 HP, 4 POLE GENERATOR

ROTOR - CONDUCTOR

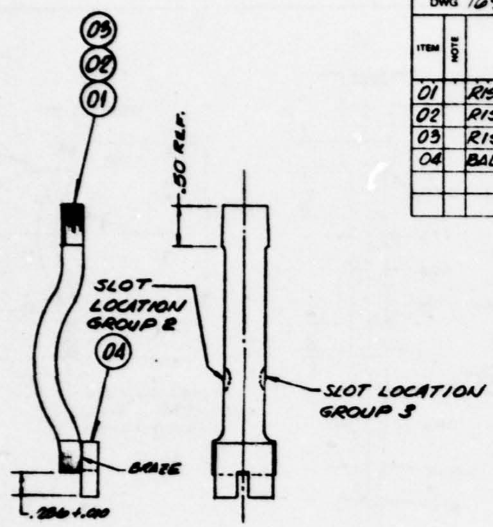
SUB.	DFTM	APPD	
	H.K. 2-10-78		
1		H.E.W. 2-21-78	
2			1.00 DIM. ADDED H.K. 4-11-78

REF DWG	TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL. DEC. ±.02	3 PL. DEC. ±.005	ANGLES ±0.5°	FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED	DIMENSIONS IN INCHES—SCALE NTS

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO.	GROUP 01	02	03	04	05



6427A25



TITLE 3000 HP, 4 POLE GENERATOR
RISER BRAZING SUB. ASSY.
DWG 1696B81 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		RISER	DWG		2616C90H01		1				
02		RISER	DWG		2616C90H02			1			
03		RISER	DWG		2616C90H03				1		
04		BALANCE BLOCK	DWG		2616C61H02		1	1	1		

1	CHANGE
D	IT.

TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL DEC ± .02 | 3 PL DEC ± .008 | ANGLES ± 0.5°

FINISH TO BE √ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG

Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
RISER BRAZING SUB. ASSY.
DIMENSIONS IN INCHES—SCALE 1:1 REV. 1

DFTR J. MARKS 3-9-78 | APPD
CHKD | APPD
SUPV | APPD

1696 B81

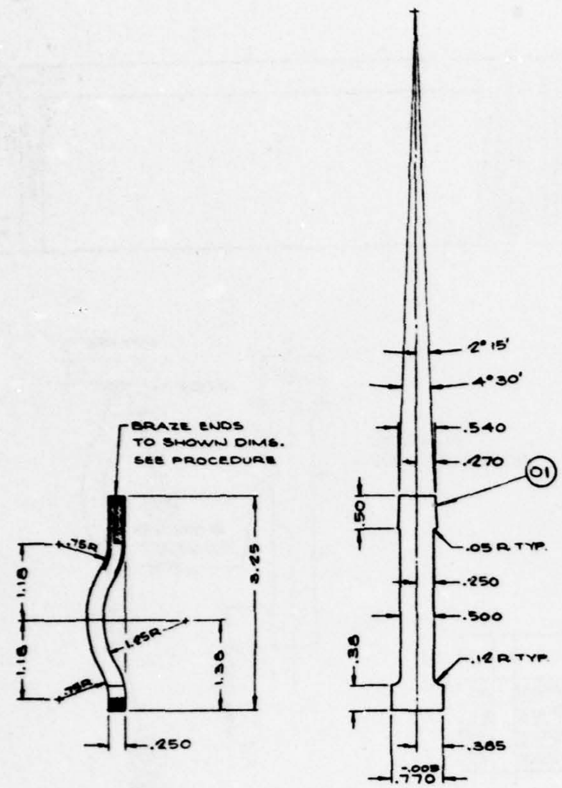
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

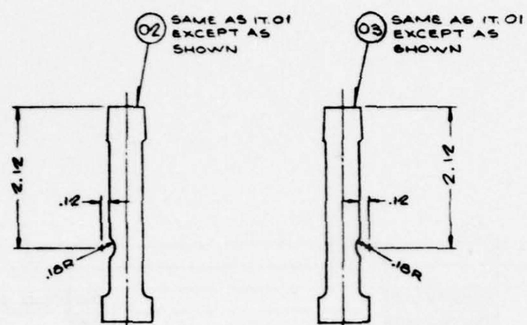
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - RISER ASSY.
DWG 2616C90 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		RISER		MAKE FROM .005 THK CU LAMINATIONS			[illegible]				
02		RISER		MAKE FROM .005 THK CU LAMINATIONS				[illegible]			
03		RISER		MAKE FROM .009 THK CU LAMINATIONS					[illegible]		

BRAZING PROCEDURE

1. CLEAN THE COPPER AS PER DWG. 6440A40 INDICATED UNDER CLEANING COPPER PARTS.
2. ASSEMBLE THE STACK OF COPPER SHEETS AND CLAMP BETWEEN COPPER BLOCKS PLACED ABOUT 1/4" FURTHER FROM THE END THAN THE DESIRED LENGTH OF CONSOLIDATION.
3. HEAT WITH OXYACETYLENE TORCH TO A TEMPERATURE OF 1340-1400°F AND FACE FEED THE JOINT AREA WITH COPPER-SILVER-PHOSPHORUS WIRE, 1/16" DIAMETER, PDS 13430JA.
4. ALLOW TO COOL, INSPECT.





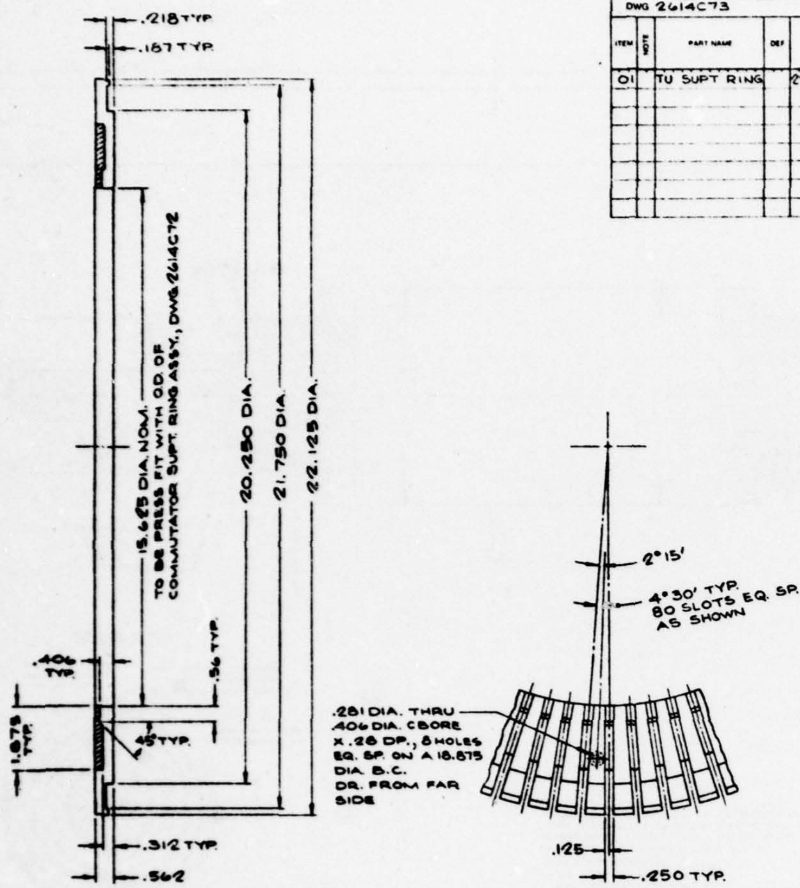
Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - RISER ASSY.
DIMENSIONS IN INCHES - SCALE 1:1 REV. 1
DFTR K. Sadowski 4-13-78
2616C90
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA. 15235 U.S.A.

TOLERANCES UNLESS OTHERWISE SPECIFIED
FINISH TO BE UNLESS OTHERWISE SPECIFIED
CHANGE

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - CONDUCTOR COOLING TUBE SUPPORT RING
DWG 2614C73 REV 1

ITEM	NOTE	PART NAME	DEF	SIZE; REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		TU SUPT RING		22.50 X 22.50 OF .75 THK MICARTA	R&D STK NO 8902-0101						

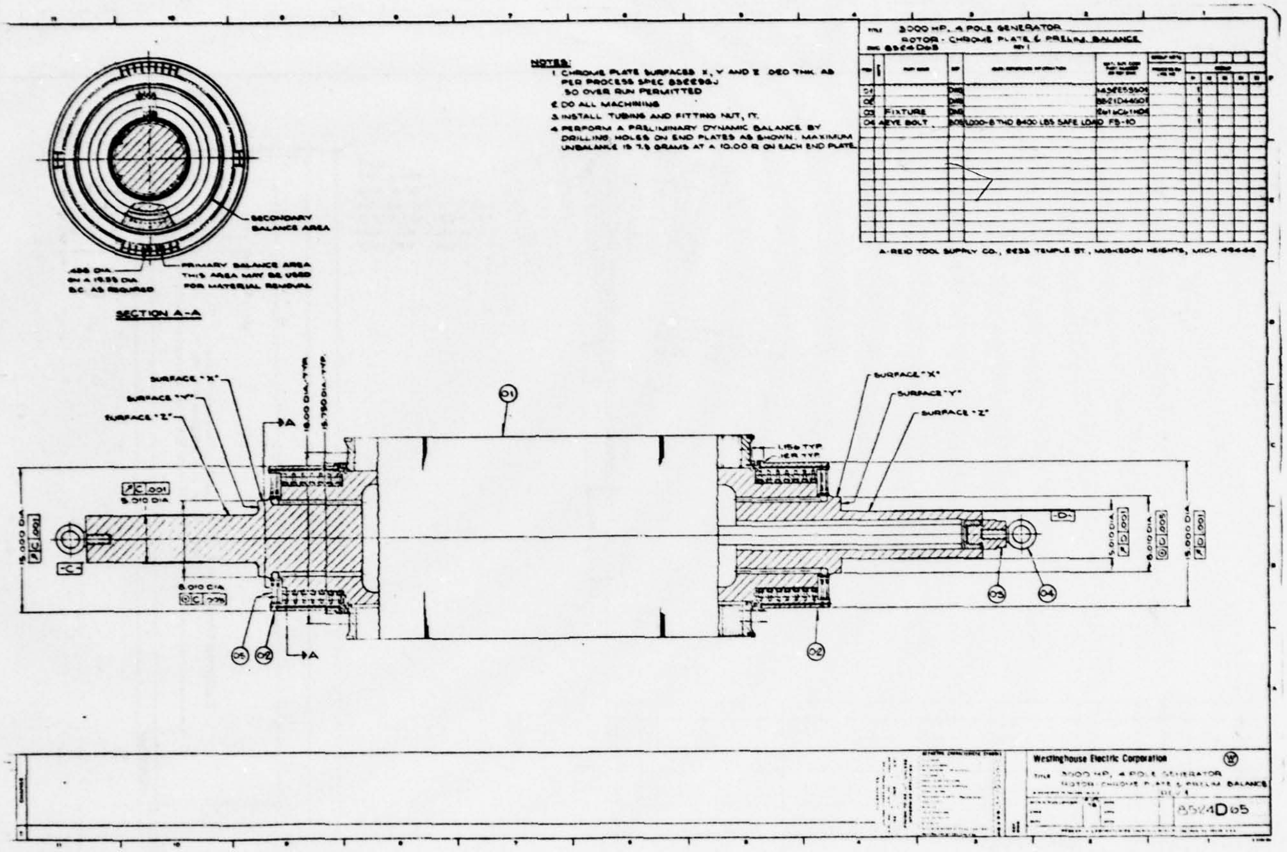


Westinghouse Electric Corporation

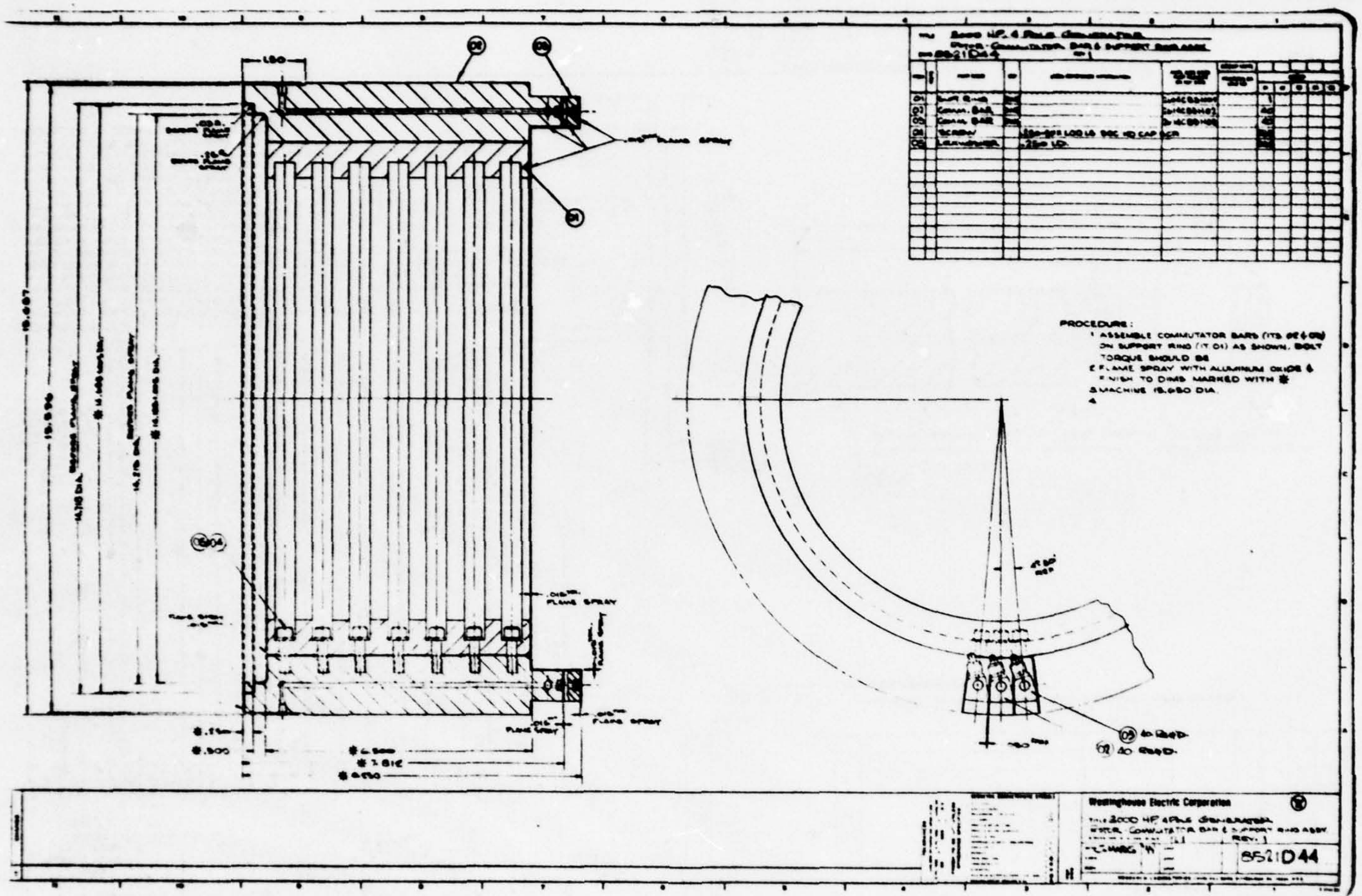
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - CONDUCTOR COOLING TUBE SUPPORT RING
SCALE 1:2 REV. 1

2614C73

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.



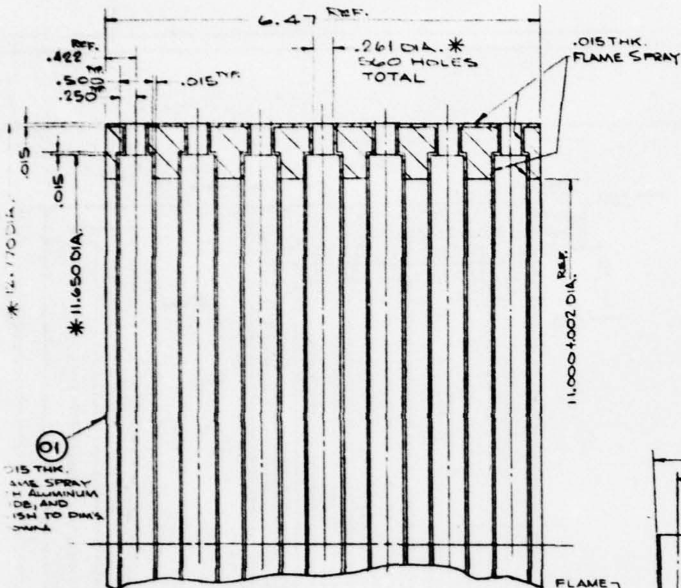
3000 HP, 4 POLE GENERATOR
ROTOR - CHROME PLATE & PRELIM. BALANCE
NOTES:
1 CHROME PLATE SURFACES X, Y AND Z .020 THK AS PER PROCESS SPEC
.50 OVER RUN PERMITTED
2 DO ALL MACHINING
3 INSTALL TUBING AND FITTING NUT, IT.
4 PERFORM A PRELIMINARY DYNAMIC BALANCE BY DRILLING HOLES ON END PLATES AS SHOWN. MAXIMUM UNBALANCE IS 7.5 GRAMS AT A 10.00 R ON EACH END PLATE
FIXTURE
EYE BOLT
8400 LBS SAFE LOAD
A-REID TOOL SUPPLY CO., 2233 TEMPLE ST., MUSKEGON HEIGHTS, MICH. 49444
SECONDARY BALANCE AREA
PRIMARY BALANCE AREA THIS AREA MAY BE USED FOR MATERIAL REMOVAL
SECTION A-A
SURFACE "X"
SURFACE "Y"
SURFACE "Z"
8.010 DIA
15.000 DIA
Westinghouse Electric Corporation
3000 HP, 4 POLE GENERATOR
ROTOR, CHROME PLATE & PRELIM. BALANCE


PROCEDURE:
1 ASSEMBLE COMMUTATOR BARS (ITS 02 & 03) ON SUPPORT RING (IT 01) AS SHOWN. BOLT TORQUE SHOULD BE
2 FLAME SPRAY WITH ALUMINUM OXIDE & FINISH TO DIMS MARKED WITH ✱
3 MACHINE 15.650 DIA.
4
03 40 REQD.
02 40 REQD.
FLAME SPRAY
1.50
Westinghouse Electric Corporation
REV. 1
8521D44

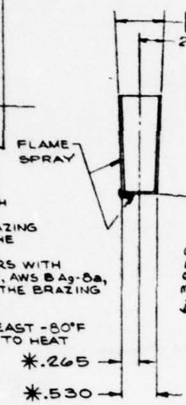
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR-SUPT. RING & COMM. BAR FLAME SPRAY DETAIL
DWG 2614C83 REV 1

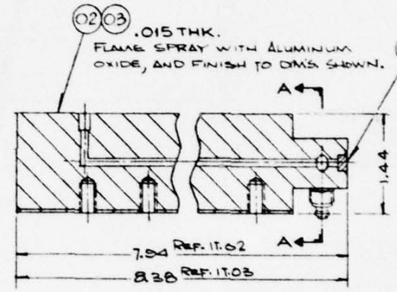
ITEM	NOTE	PART NAME	DET	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		SUPT. RING	DWG		8521D26H01		1				
02		COMM. BAR	DWG		8521D26H02		1				
03		COMM. BAR	DWG		8521D26H03		1				
04		PLUG	DWG		8521D26H05		1				
05		FITTING	DWG		8521D22H02		1				

NOTE:
1. ALL DIMS. MARKED WITH * AFTER FLAME SPRAYING, MACHINE IF NECESSARY

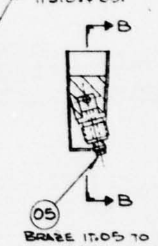


BRAZING PROCEDURE:
1. CLEAN ALL PARTS AS PER DWG 6440A40 INDICATED UNDER CLEANING COPPER PARTS AND CLEANING STAINLESS STEEL PARTS.
2. ASSEMBLE THE STAINLESS STEEL FITTINGS TO THE COPPER BARS WITH A WASHER OF .003" THICK 71.8 Ag-28 Cu-0.2 Li BRAZING ALLOY (AWS CLASS B Ag-8a) AT EACH JOINT. I.D. AND O.D. DIMENSIONS OF BRAZING ALLOY WASHER SHOULD ROUGHLY MATCH THOSE OF THE BASE OF THE FITTING. NO FLUX NEEDED.
3. ASSEMBLE THE COPPER PLUGS INTO THE ENDS OF THE COPPER BARS WITH A RING OF 1/32" DIA. WIRE BRAZING ALLOY, 71.8 Ag-28 Cu-0.2 Li, AWS B Ag-8a, AT THE JOINT CIRCUMFERENCE. A GROOVE MACHINED TO CONTAIN THE BRAZING ALLOY WOULD BE OF CONSIDERABLE HELP. NO FLUX NEEDED.
4. FIXTURE THE BARS VERTICALLY WITH THE PLUG END UP.
5. FURNACE BRAZE IN HYDROGEN WITH A DEW POINT OF AT LEAST -80°F (-60°C) AT A TEMPERATURE OF 1450°F. HOLD LONG ENOUGH TO HEAT ALL PARTS TO TEMPERATURE.
6. COOL IN HYDROGEN, INSPECT.





SECTION B-B



SECTION A-A

CHANGE

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

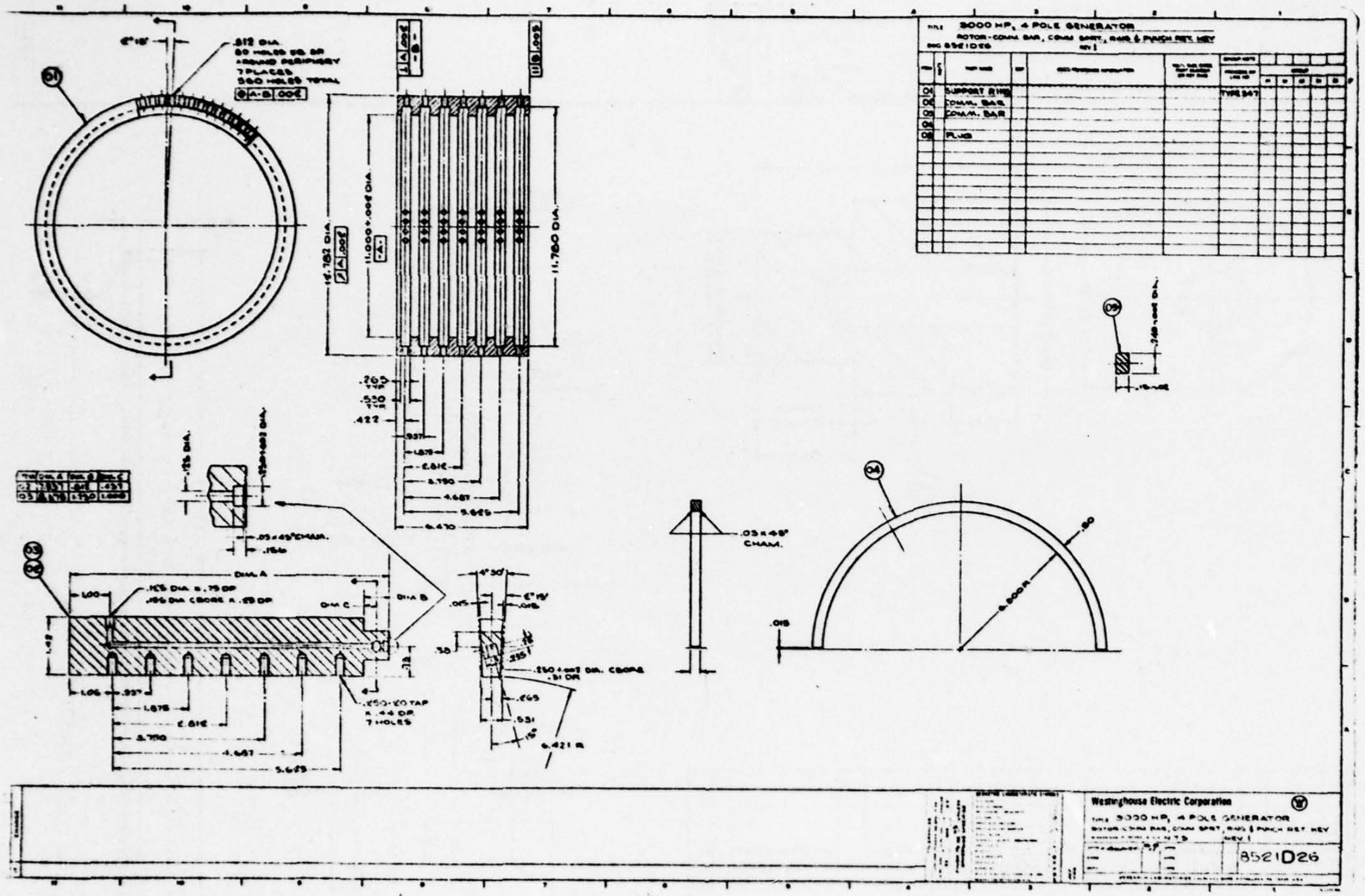
REF DWG 8521D44

Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR-SUPT. RING & COMM. BAR FLAME SPRAY DETAIL
DIMENSIONS IN INCHES—SCALE 1:1 REV. 1
DFTR J. MARKS 10-26-77
CHKD
SUPV
APPD
APPD
AUTH

2614C83

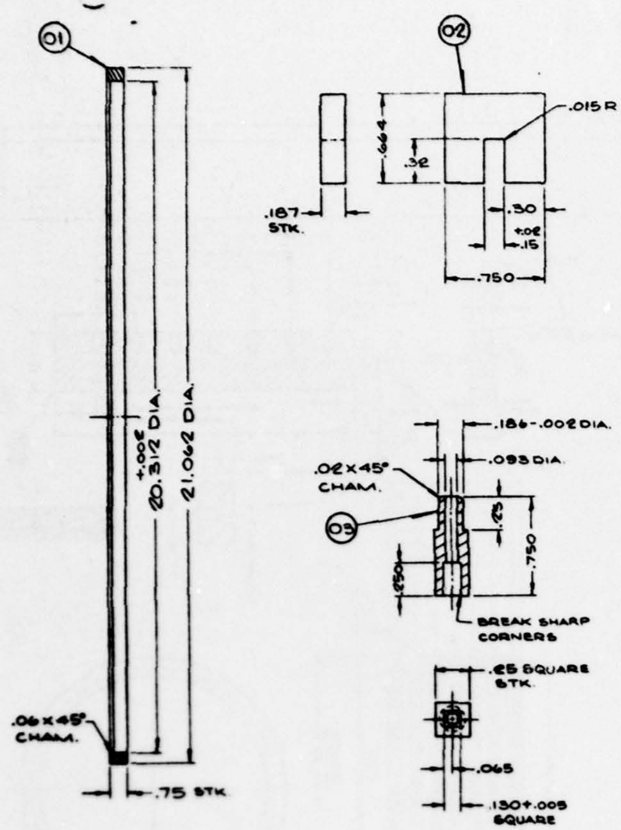
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

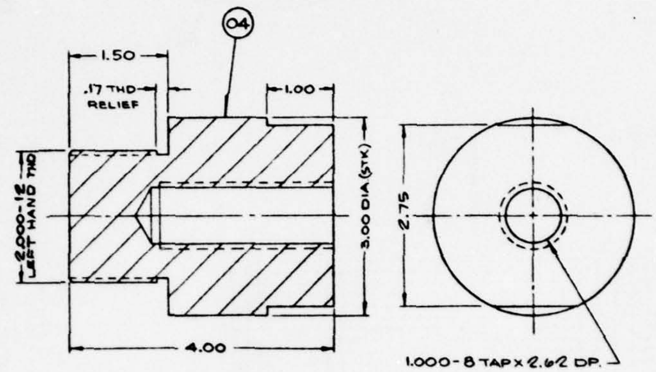


3000 HP, 4 POLE GENERATOR
ROTOR-COMM BAR, COMM SPRT, RING & PUNCH RET. KEY
DWG 8521D26
SUPPORT RING
COMM. BAR
COMM. BAR
PLUG
TYPE 347
.812 DIA.
80 HOLES EQ. SP.
AROUND PERIPHERY
7 PLACES
560 HOLES TOTAL
14.182 DIA.
11.000+.002 DIA.
11.760 DIA.
DIA. A
DIA. B
DIA. C
.125 DIA. x .75 DP
.156 DIA. CBORE x .25 DP
.250-20 TAP
x .44 DP
7 HOLES
.03 x 45° CHAM.
.03 x 45°
CHAM.
6.421 R
6.300 R
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR-COMM BAR, COMM SPRT, RING & PUNCH RET. KEY
8521D26

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - INSUL RING, BAL BLOCK, ADAPTER & FIXTURE DETS
DWG 2616C61 REV 1

ITEM	NOTE	PART NAME	DET	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG R&D STK NO	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		INSUL RING		21.25 x 21.25 OF .75 THK MICARTA	5902-0101	GR 221					
02		BALANCE BLOCK		.88 OF .187 x .750 BRASS BAR	6009-0901	ASTM B-16					
03		ADAPTER		1.00 OF .250 DIA BRASS BAR	5905-1101	ASTM B-16					
04		ROTOR FIXTURE		4.12 OF 3.00 DIA CR STL ROD	5902-0101	ANSI B1113					



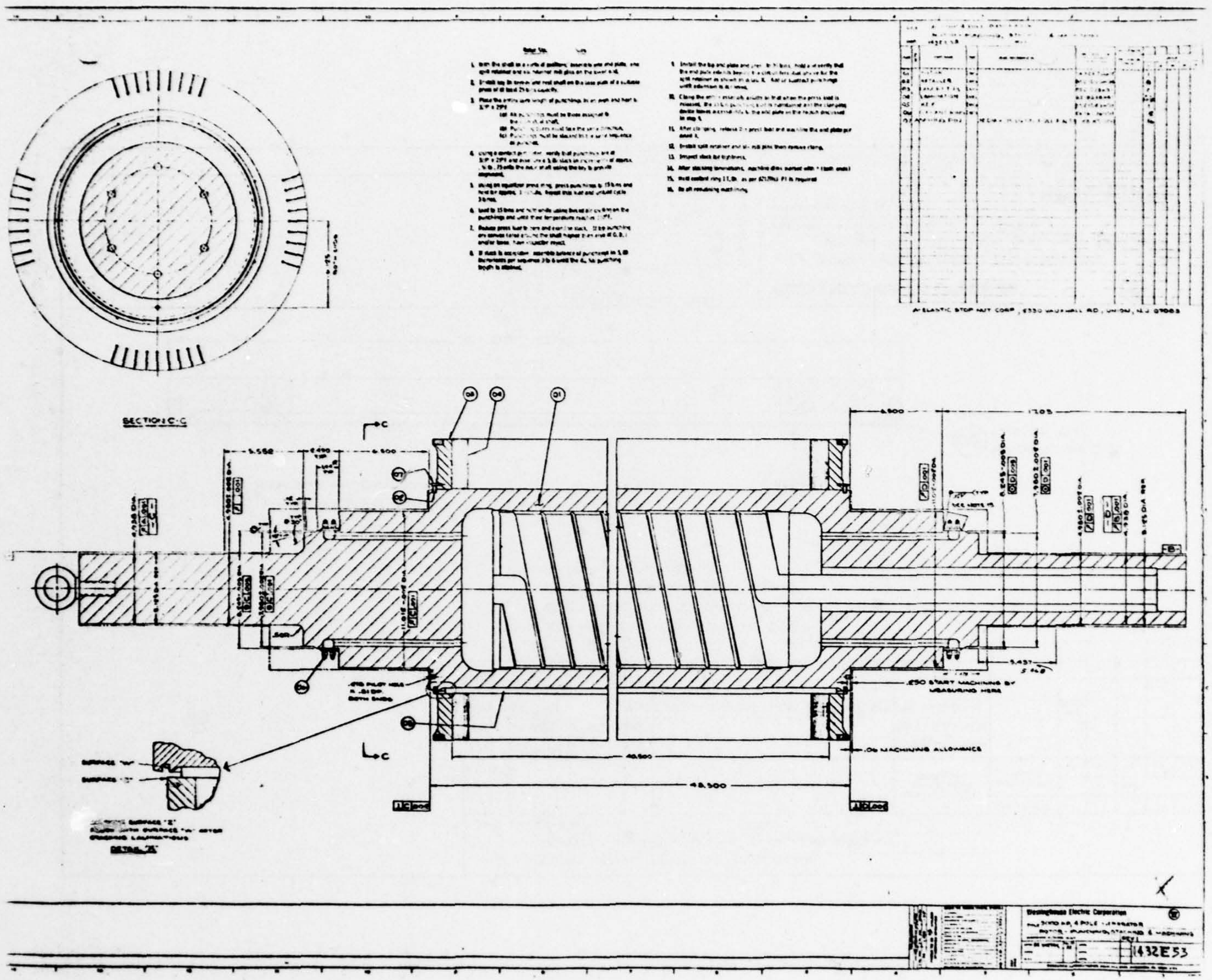


Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR-INSUL RING, BAL BLOCK, ADAPTER & FIXTURE DETS
DIMENSIONS IN INCHES-SCALE NTS REV 1
DFTM H.KOZLOWSKI 3-21-78
2616C61

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 USA

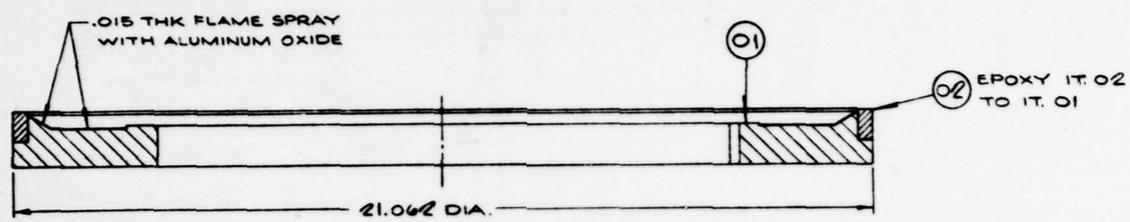
FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED


SECTION C-C
DETAIL "A"
.250 START MACHINING BY MEASURING HERE
.06 MACHINING ALLOWANCE
40.500
48.500
ATLANTIC STOP NUT CORP., 2330 VAUXHALL RD., UNION, N.J. 07083
Westinghouse Electric Corporation
1432E53

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR-RET. PL. ASSY. & FLAME SPRAY
DWG 1696B46 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		RET PLATE	DWG		B521D23H01		1				
02		INSUL RING	DWG		2616C61H01		1				
03	A	EPOXY	BOSB-280-2 CLEAR HEAT REACTIVE EPOXY VARNISH				AS REQ				

A- WESTINGHOUSE ELECTRIC CORP.
INDUSTRIAL PLASTICS DIV.
CHEMICAL PRODUCTS PLANT
MANOR, PA. 15665



1	CHANGE
D.	IT.

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL. DEC. ±.03; 3 PL. DEC. ±.005; ANGLES ±0.5°

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG 1432E53

Westinghouse Electric Corporation

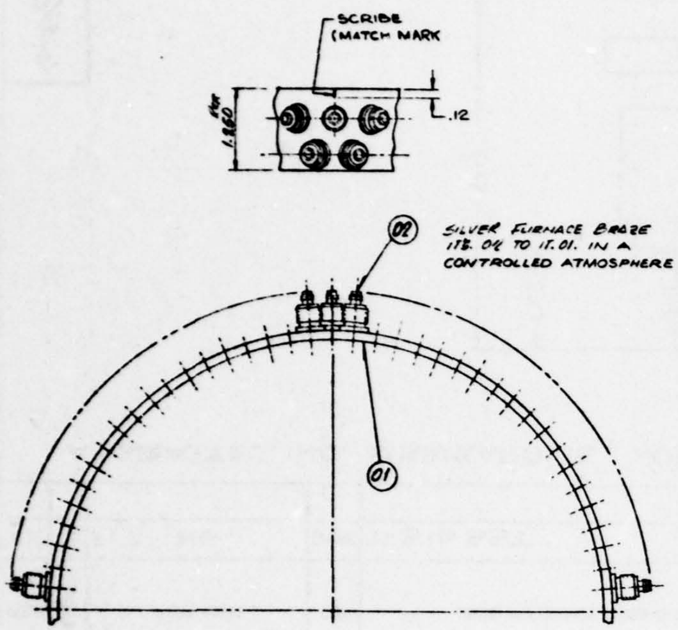
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR-RET. PL. ASSY. & FLAME SPRAY
DIMENSIONS IN INCHES—SCALE 1:2 REV. 1
DFTR H. KOSLOWSKI 4-10-78 APPD
CHKD APPD
SUPV APPD

1696B46

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA. 15235 U.S.A.

TITLE 3,000 HP - 4 POLE GENERATOR
ROTOR - COOLANT RING BRAZE ASSY
DWG 2616C76 REV

ITEM	QTY	PART NAME	DEF	DATA / REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER ON KEY DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		COOLANT RING	DWG		8521D22H01		1				
02		FITTING	DWG		6426A23H01		80				



BRAZING PROCEDURE

1. CLEAN THE PARTS AS PER DWG 6440A40 INDICATED UNDER CLEANING STAINLESS STEEL PARTS.
2. ASSEMBLE THE FITTINGS TO THE HALF RING SEGMENT WITH A .003" THICK WASHER OF 71.8% Ag - 28% Cu - 0.2% Li (AWS CLASS B Ag-8a) BRAZING ALLOY BETWEEN EACH FITTING AND THE RING. THE WASHER ID AND OD SHOULD APPROXIMATE THE ID AND OD DIMENSIONS OF THE JOINT.
3. ADD A RING FORMED OF 1/32" DIAMETER WIRE OF THE 71.8% Ag - 28% Cu - 0.2 Li BRAZING ALLOY TO EACH JOINT. THIS RING SHOULD BE FORMED TO FIT SNUGLY AROUND THE BASE OF THE FITTING WHERE IT CONTACTS THE RING. NO FLUX NEEDED.
4. FURNACE BRAZE IN A HYDROGEN ATMOSPHERE WITH A -80°F (-60°C) DEW POINT AT A TEMPERATURE OF 1450°F. HEAT LONG ENOUGH TO OBTAIN UNIFORM TEMP. THROUGHOUT.
5. ALLOW TO COOL IN HYDROGEN, INSPECT.

CHANGE

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

REF DWG 1432E53

Westinghouse Electric Corporation

TITLE 3,000 HP - 4 POLE GENERATOR
ROTOR - COOLANT RING BRAZE ASSY

DIMENSIONS IN INCHES—SCALE

DFTR J. MARKS '78

2616C76

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

20

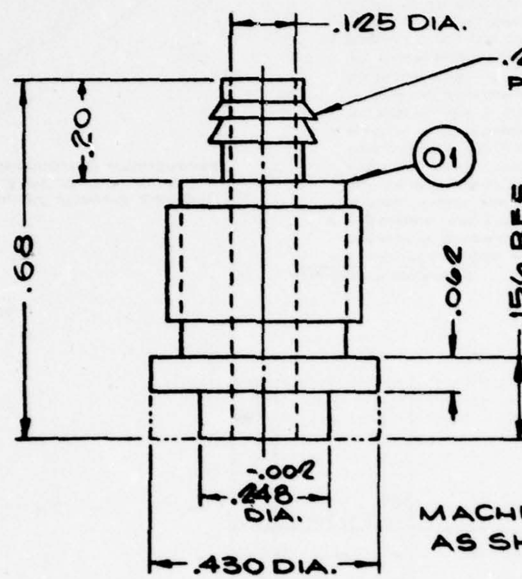
Westinghouse Electric Corporation R&D CENTER. 1310 BEULAH RD., PITTSBURGH, PA. 15235 USA

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR, COMMUTATOR COOLANT FITTING

REF DWG	TOLERANCES UNLESS OTHERWISE SPECIFIED			FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED	DIMENSIONS IN INCHES—SCALE	DFTM H K	APPD
	2 PL. DEC.	3 PL. DEC.	ANGLES		4:1	SUB.	1
	±.02	±.005	±0.5°				

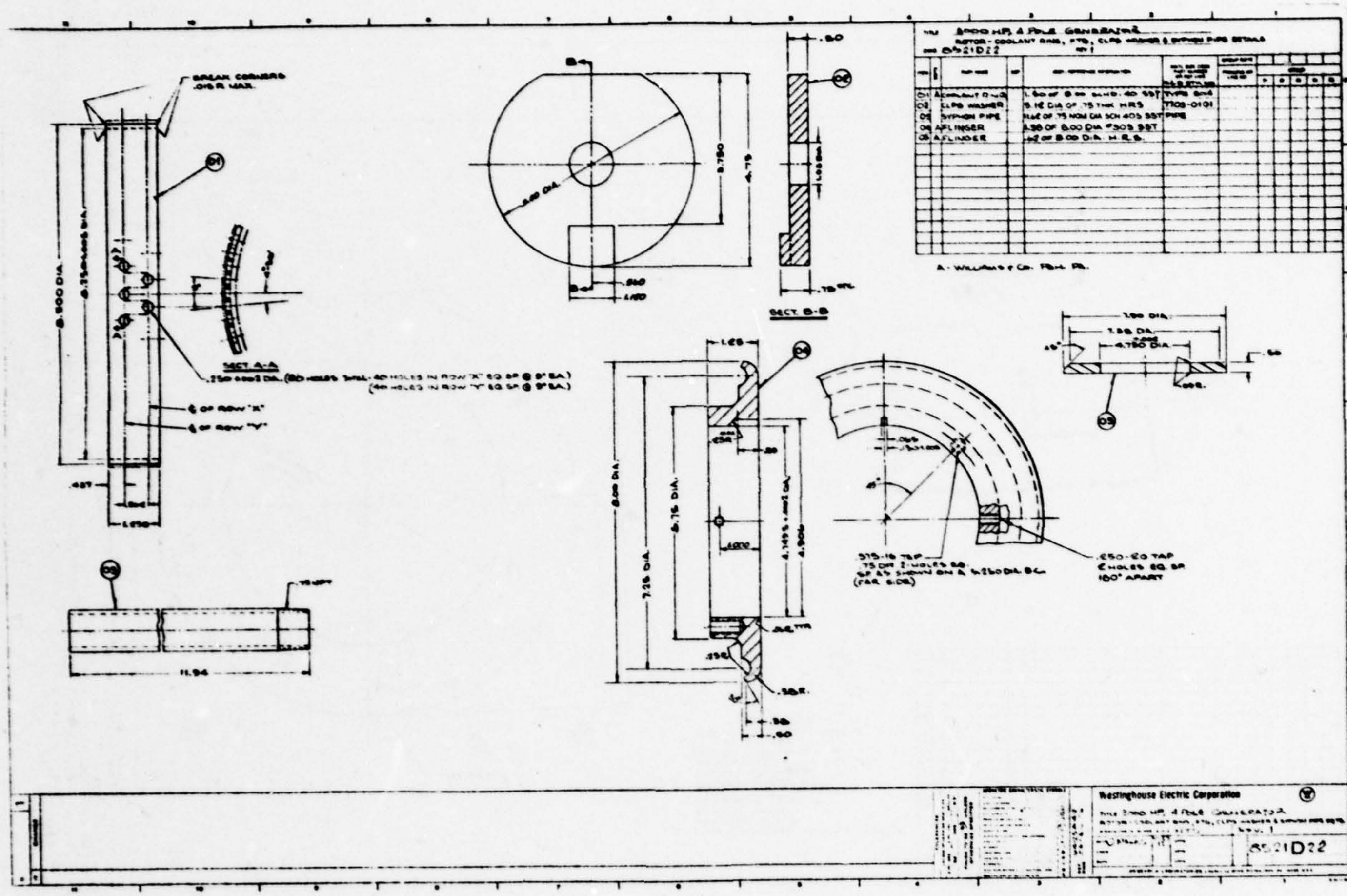
ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01	A	FITTING	808	T-316 SST							

A-GRA-TEC, INC. MINNEAPOLIS, MIN. 55428

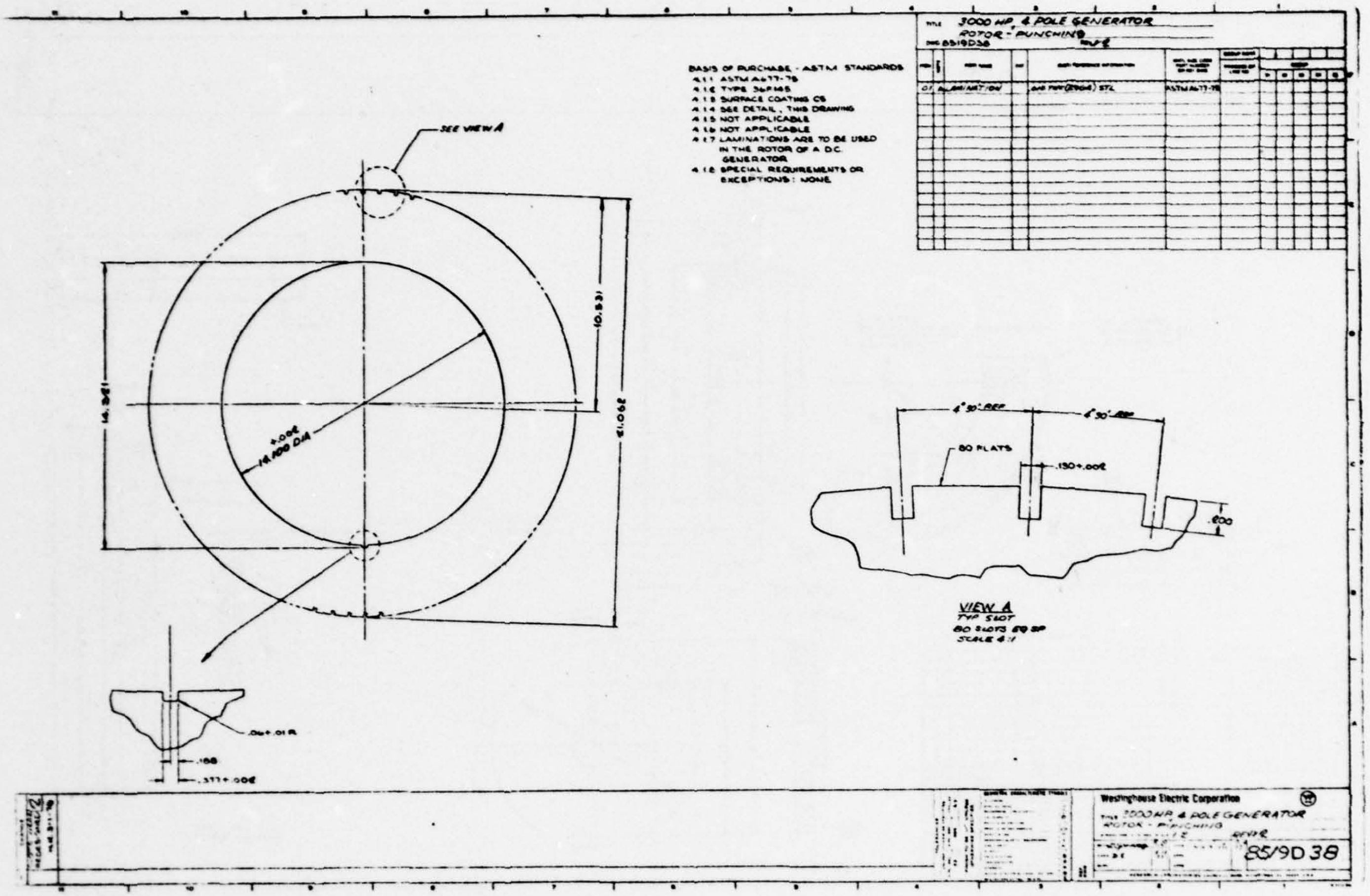


MACHINE END
AS SHOWN

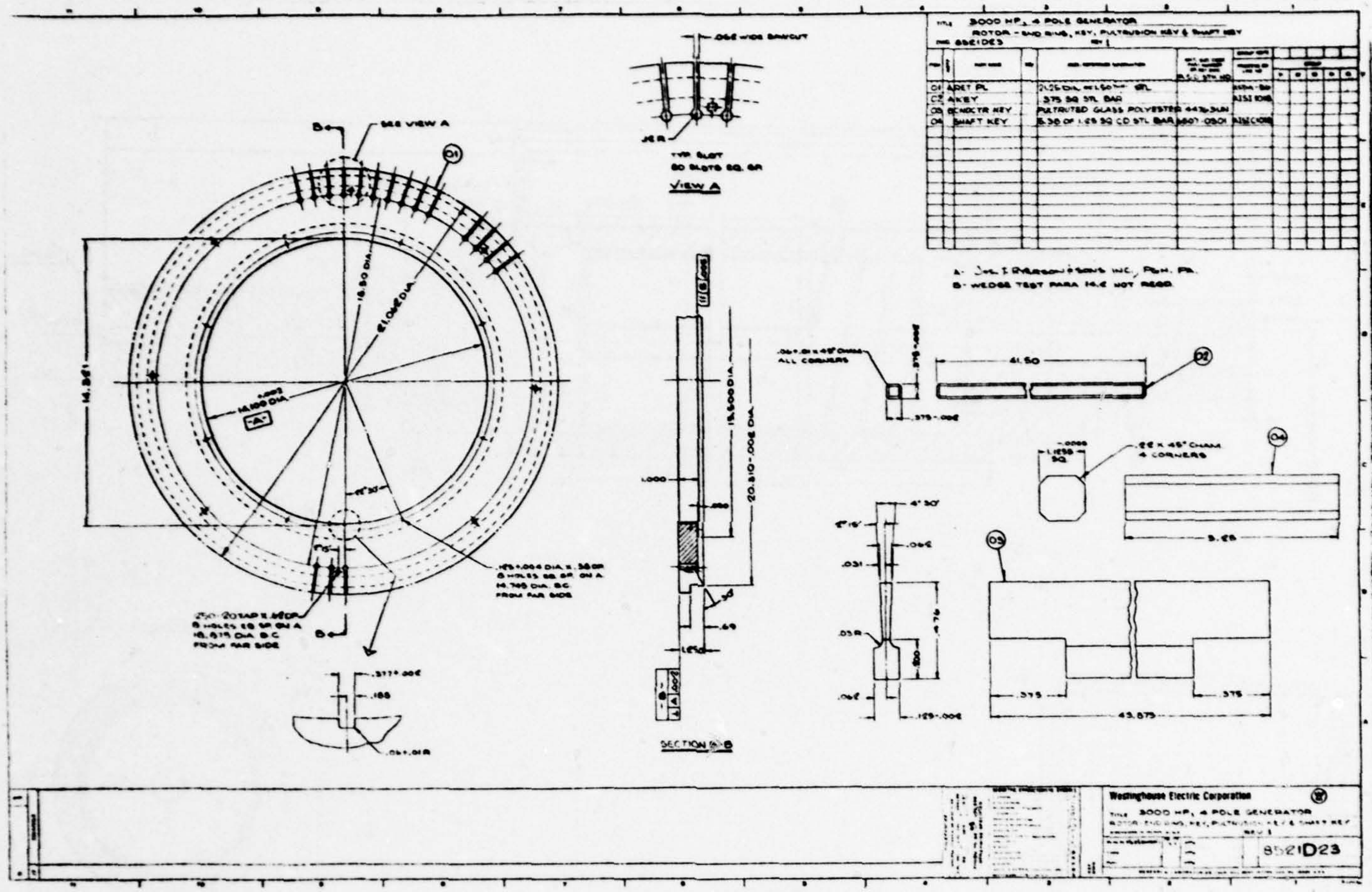
6426A48



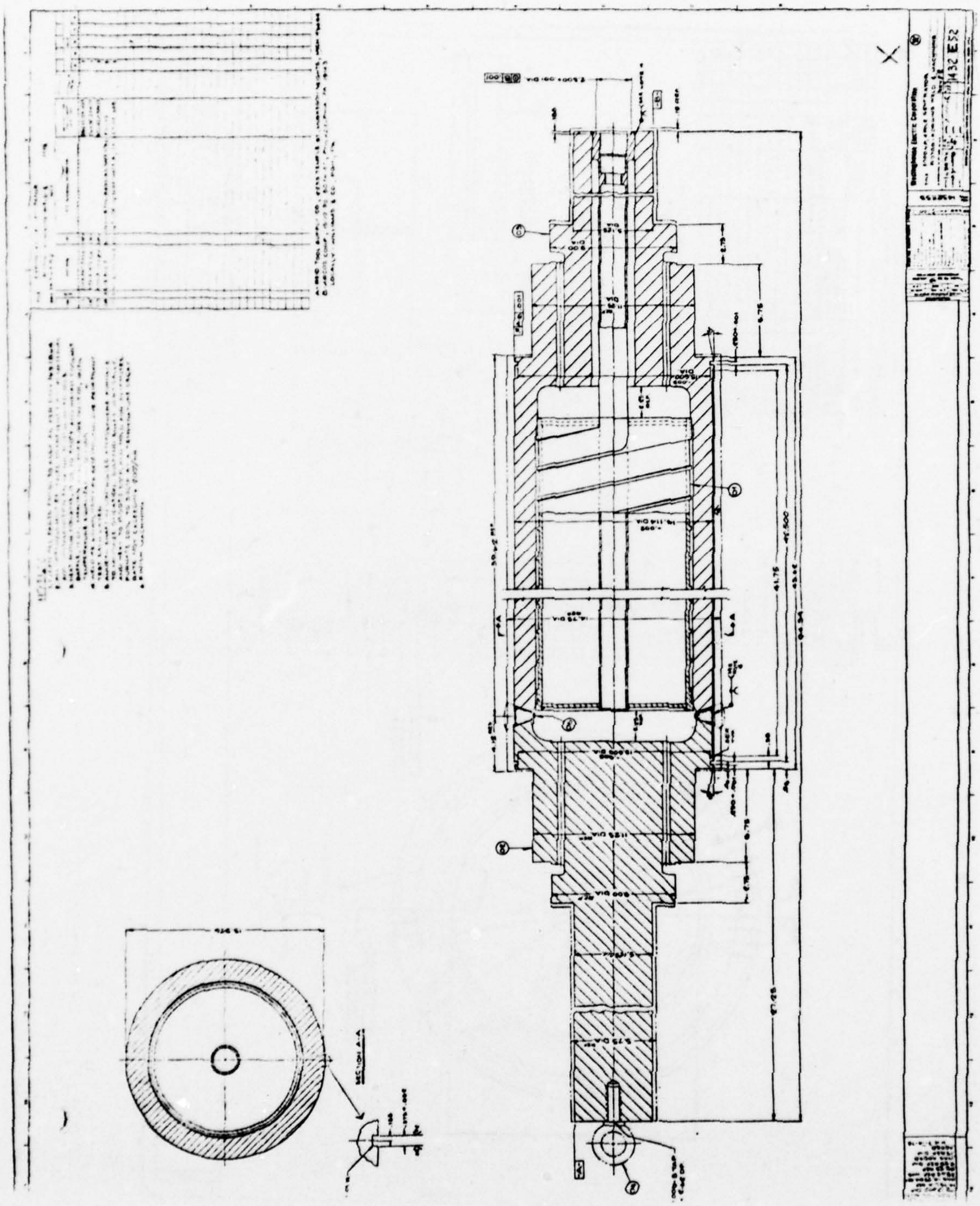
8000 H.P. 4 POLE GENERATOR
ROTOR - COOLANT RING, FTG, CLPG WASHER & SYPHON PIPE DETAILS
8521D22
01 COOLANT RING
02 CLPG WASHER
03 SYPHON PIPE
04 A FLINGER
05 A FLINGER
15.16 DIA OF .75 THK H.R.S.
OF .75 NOM DIA SCH 40S SST PIPE
OF 8.00 DIA #303 SST
OF 8.00 DIA H.R.S.
T105-0101
A. WILLIAMS & CO. PGH. PA.
BREAK CORNERS .015 R. MAX.
8.500 DIA.
SECT. A-A
¢ OF ROW "X"
¢ OF ROW "Y"
11.94
SECT. B-B
8.00 DIA.
7.25 DIA.
6.75 DIA.
7.50 DIA.
4.750 DIA.
.250-20 TAP
6 HOLES EQ. SP.
100° APART
Westinghouse Electric Corporation
8000 HP. 4 POLE GENERATOR
8521D22

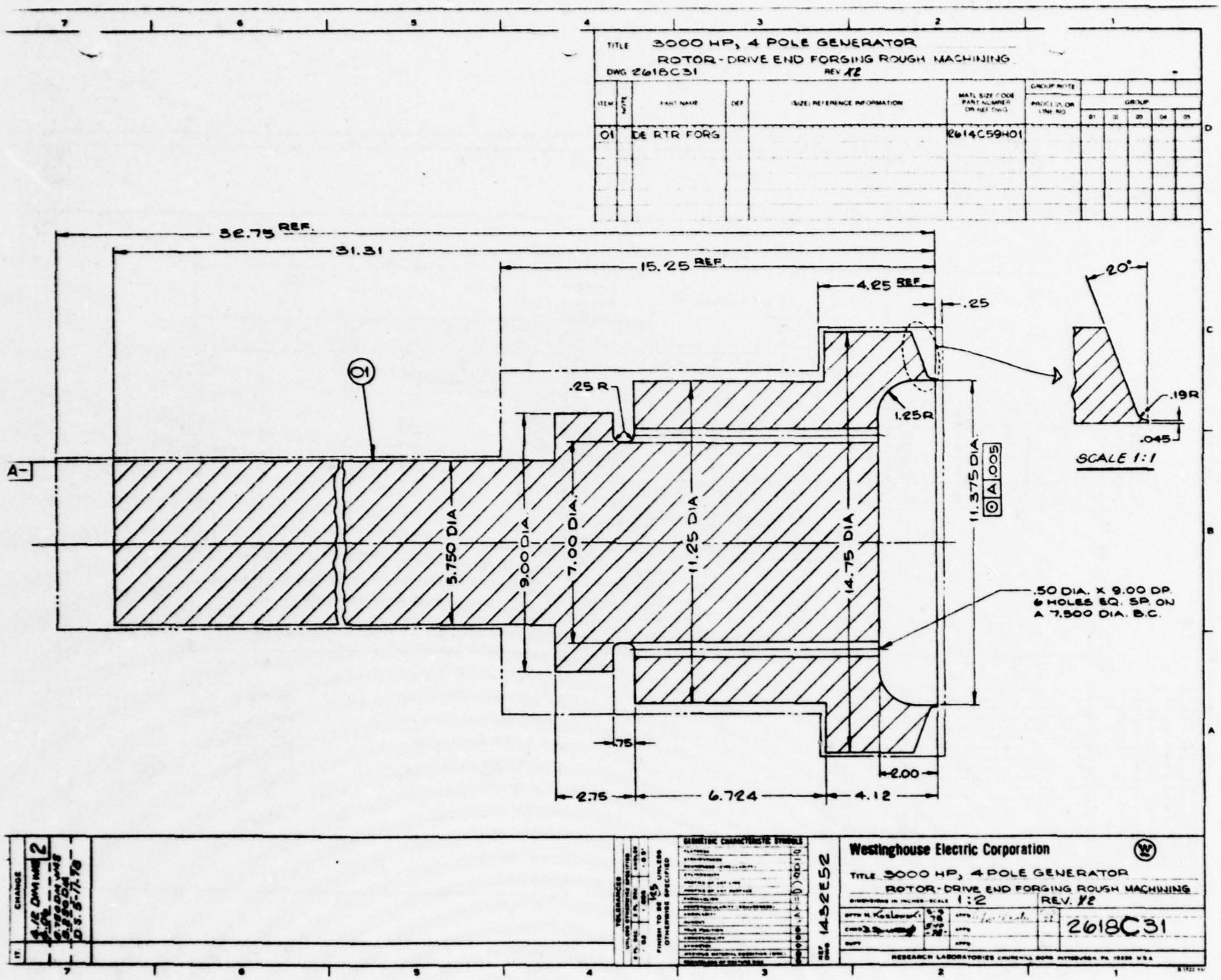


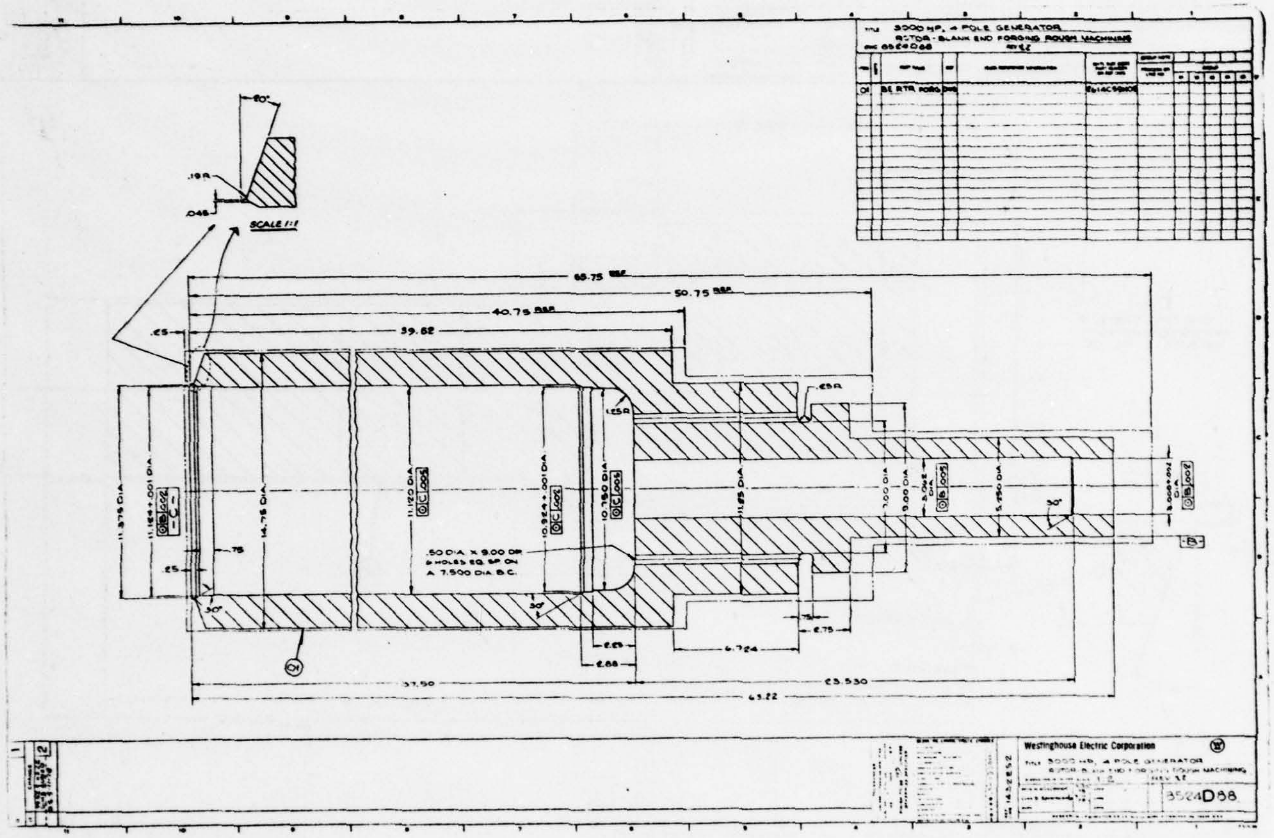
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - PUNCHING
DWG 8519D38
BASIS OF PURCHASE - ASTM STANDARDS
4.1.1 ASTM A677-78
4.1.2 TYPE 36F145
4.1.3 SURFACE COATING C5
4.1.4 SEE DETAIL, THIS DRAWING
4.1.5 NOT APPLICABLE
4.1.6 NOT APPLICABLE
4.1.7 LAMINATIONS ARE TO BE USED IN THE ROTOR OF A D.C. GENERATOR
4.1.8 SPECIAL REQUIREMENTS OR EXCEPTIONS: NONE
01 LAMINATION
ASTM A677-78
SEE VIEW A
10.531
21.062
14.100 DIA
80 FLATS
.130+.002
.200
VIEW A
TYP SLOT
80 SLOTS EQ SP
SCALE 4:1
.188
Westinghouse Electric Corporation
3000 HP, 4 POLE GENERATOR
ROTOR - PUNCHING
8519D38



TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - END RING, KEY, PULTRUSION KEY & SHAFT KEY
01 ADPT PL
02 A KEY
03 BCNDCTR KEY
04 SHAFT KEY
.375 SQ STL BAR
PULTRUTED GLASS POLYESTER
AISI 1018
A- JOS. T. RYERSON & SONS INC., PGH. PA.
B- WEDGE TEST PARA 14.E NOT REQD.
SEE VIEW A
15.50 DIA
21.062 DIA
14.100 DIA
14.361
TYP SLOT
80 SLOTS EQ. SP.
VIEW A
.062 WIDE SAWCUT
FROM FAR SIDE
SECTION B-B
19.500 DIA.
20.810-.002 DIA.
1.000
41.50
ALL CORNERS
.375-.002
4 CORNERS
5.25
43.875
.375
.129-.002
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
REV 1
8521D23

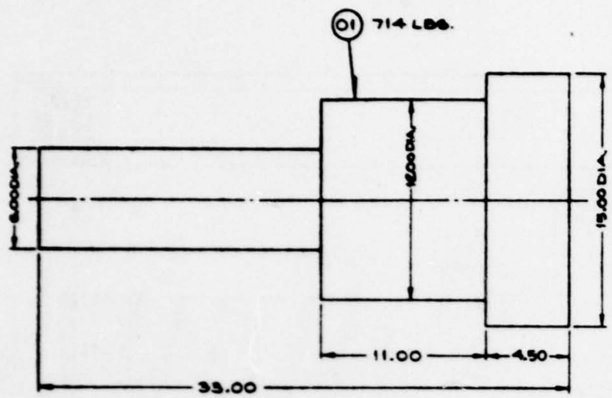



TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - DRIVE END FORGING ROUGH MACHINING
DWG 2618C31
REV 12
01 DE RTR FORG 2614C59H01
32.75 REF.
31.31
15.25 REF.
4.25 REF
.25
.25 R
1.25R
11.375 DIA
A .005
5.750 DIA
9.00 DIA
7.00 DIA
11.25 DIA
14.75 DIA
.50 DIA. X 9.00 DP.
6 HOLES EQ. SP. ON
A 7.500 DIA. B.C.
.75
2.00
2.75
6.724
4.12
20°
.19R
.045
SCALE 1:1
A-
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - DRIVE END FORGING ROUGH MACHINING
1:2
REV. 12
2618C31
1432E52
RESEARCH LABORATORIES

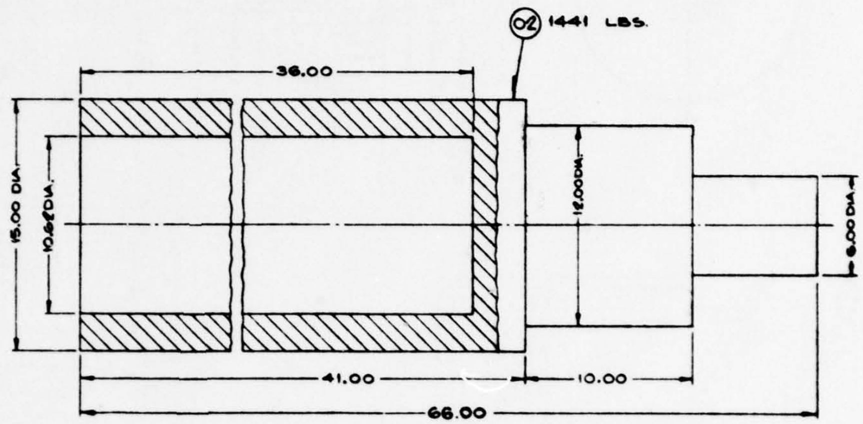

5000 HP, 4 POLE GENERATOR
ROTOR - BLANK END FORGING ROUGH MACHINING
01
BE RTR FORG
SCALE 1:1
.19R
.048
60°
68.75 REF
50.75 REF
40.75 REF
39.62
.25
11.375 DIA
11.164 +.001 DIA
14.75 DIA
11.120 DIA
10.924 +.001 DIA
10.750 DIA
.50 DIA X 9.00 DP
6 HOLES EQ. SP. ON
A 7.500 DIA. B.C.
1.25R
.63R
11.25 DIA
7.00 DIA
9.00 DIA
5.950 DIA
30°
B
4.724
6.75
37.50
63.530
63.22
Westinghouse Electric Corporation
3524D88
1432E52

TITLE 3000 HP - 4 POLE GENERATOR
ROTOR - SHAFT FORGING
DWG 2614C59 REV 4

ITEM	NOTE	PART NAME	DEF	(NAS) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP
01		RTR FORG DE		STAINLESS STEEL		TYPE 347	
02		RTR FORG BE		STAINLESS STEEL		TYPE 347	



ORDERING DATA:
- 3.1.1 ROTOR SHAFT
- 3.1.2 ASTM A182 F347
- 3.1.3 SEE DETAILS (IT. 01 & 02 THIS DWG.) FOR SIZE & GEOMETRY
- 3.1.4 SEE PURCHASE ORDER FOR QUANTITY
- 3.1.5 CERTIFIED CHEMICAL & PHYSICAL TEST REPORTS & CERTIFICATION OF ULTRASONIC TESTING IS REQUIRED
- 3.1.6 SUPPLEMENTARY REQUIREMENTS
  PERFORM ULTRASONIC INSPECTION PER ASME BOILER & PRESSURE VESSEL CODE SECTION III, SUB SECTION NB PARA NB2542



CHANGE
02 10.00 DIA WAS 7.00
2
3
4

TOLERANCES
FINISH TO BE UNLESS OTHERWISE SPECIFIED

REF DWG 1432E52

Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - SHAFT FORGING
SCALE 1:4 REV. 4

2614C59

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 USA

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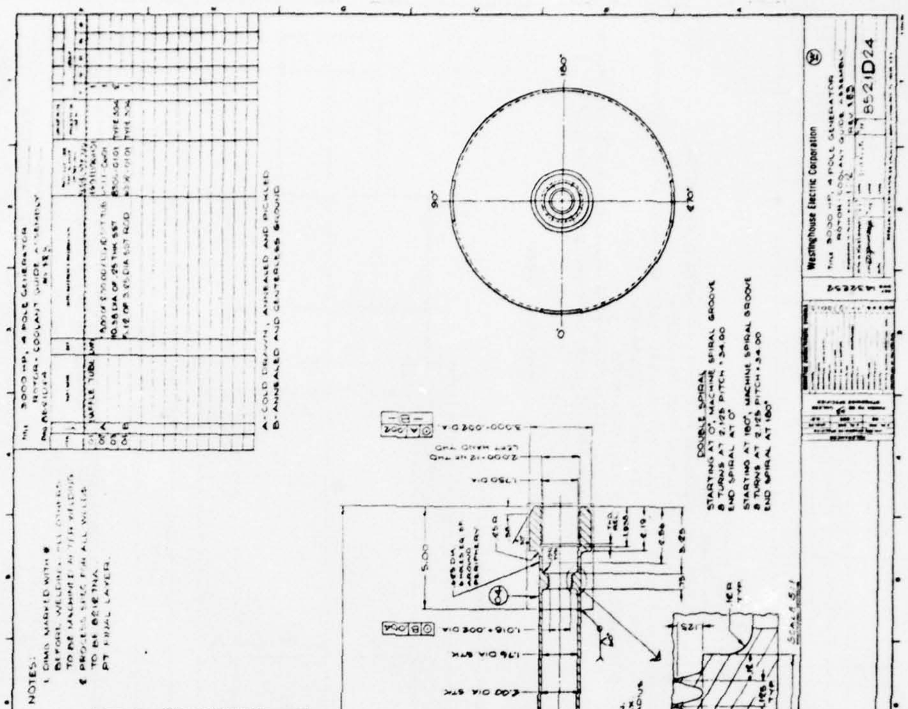
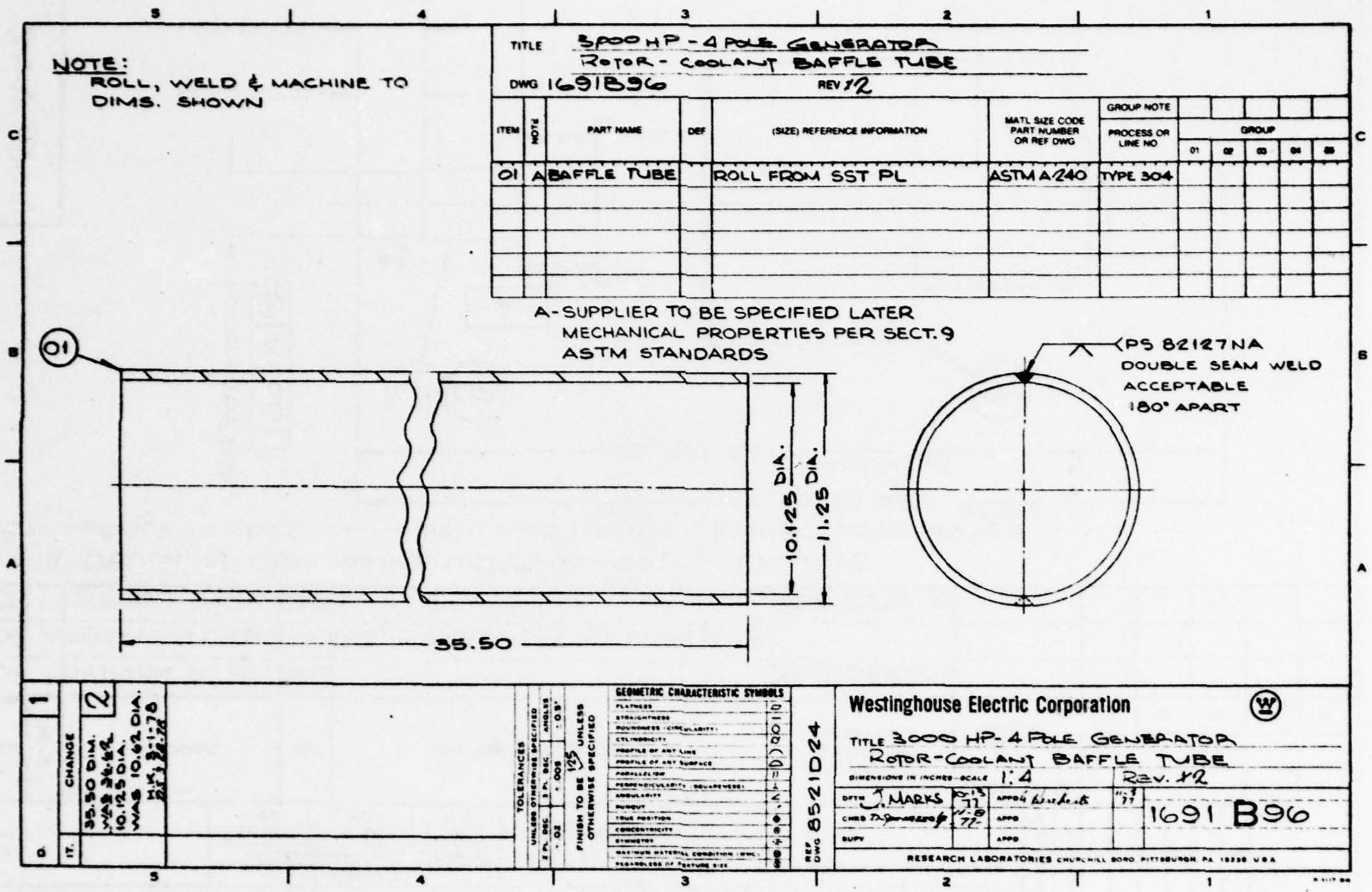



NOTE:
ROLL, WELD & MACHINE TO DIMS. SHOWN
TITLE 3000 HP - 4 POLE GENERATOR ROTOR - COOLANT BAFFLE TUBE
DWG 1691B96 REV #2
ITEM NOTE PART NAME DEF (SIZE) REFERENCE INFORMATION MAT'L SIZE CODE PART NUMBER OR REF DWG GROUP NOTE PROCESS OR LINE NO GROUP 01 02 03 04 05
01 A BAFFLE TUBE ROLL FROM SST PL ASTM A240 TYPE 304
A-SUPPLIER TO BE SPECIFIED LATER
MECHANICAL PROPERTIES PER SECT. 9
ASTM STANDARDS
01
10.125 DIA.
11.25 DIA.
35.50
PS 82127NA
DOUBLE SEAM WELD
ACCEPTABLE
180° APART
1
2
CHANGE
35.50 DIM. WAS 36.62
10.125 DIA. WAS 10.62 DIA.
TOLERANCES
FINISH TO BE 125 UNLESS OTHERWISE SPECIFIED
GEOMETRIC CHARACTERISTIC SYMBOLS
REF DWG 8521D24
Westinghouse Electric Corporation
TITLE 3000 HP- 4 POLE GENERATOR ROTOR-COOLANT BAFFLE TUBE
DIMENSIONS IN INCHES-SCALE 1:4
Rev. #2
DFTM J. MARKS
1691 B96
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

30

Westinghouse Electric Corporation R&D CENTER. 1310 BEULAH RD., PITTSBURGH, PA. 15235 USA

TITLE 3000 HP, 4 POLE GENERATOR & 6 POLE MOTOR
ROTOR - ROTATING UNION

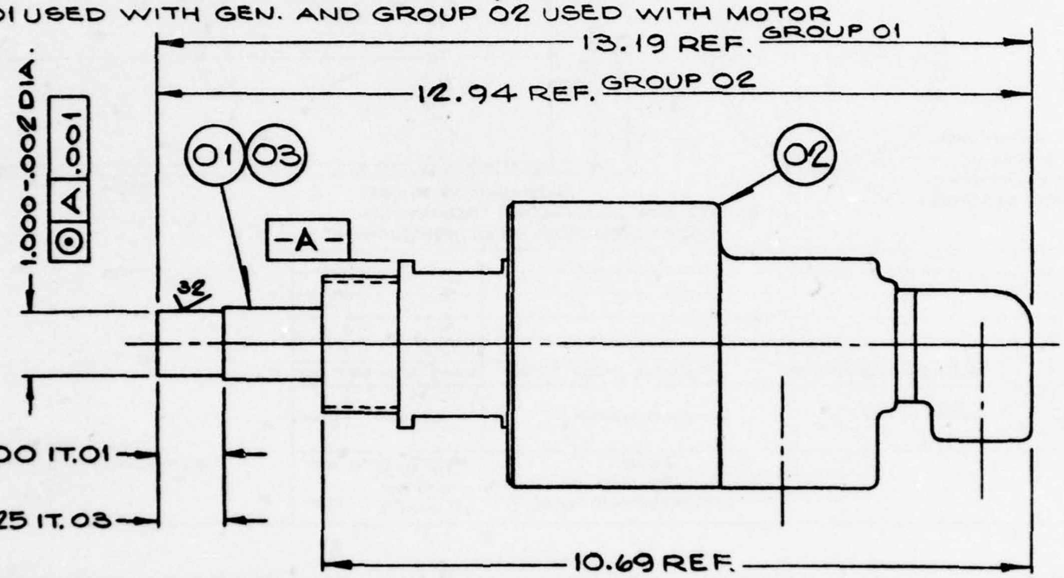
DFTM H.K. 1-11-78 | APPD
SUB. 1

REF DWG	TOLERANCES UNLESS OTHERWISE SPECIFIED			FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED	DIMENSIONS IN INCHES—SCALE
	2 PL. DEC.	3 PL. DEC.	ANGLES		
	± .02	± .005	± 0.5°		1:2

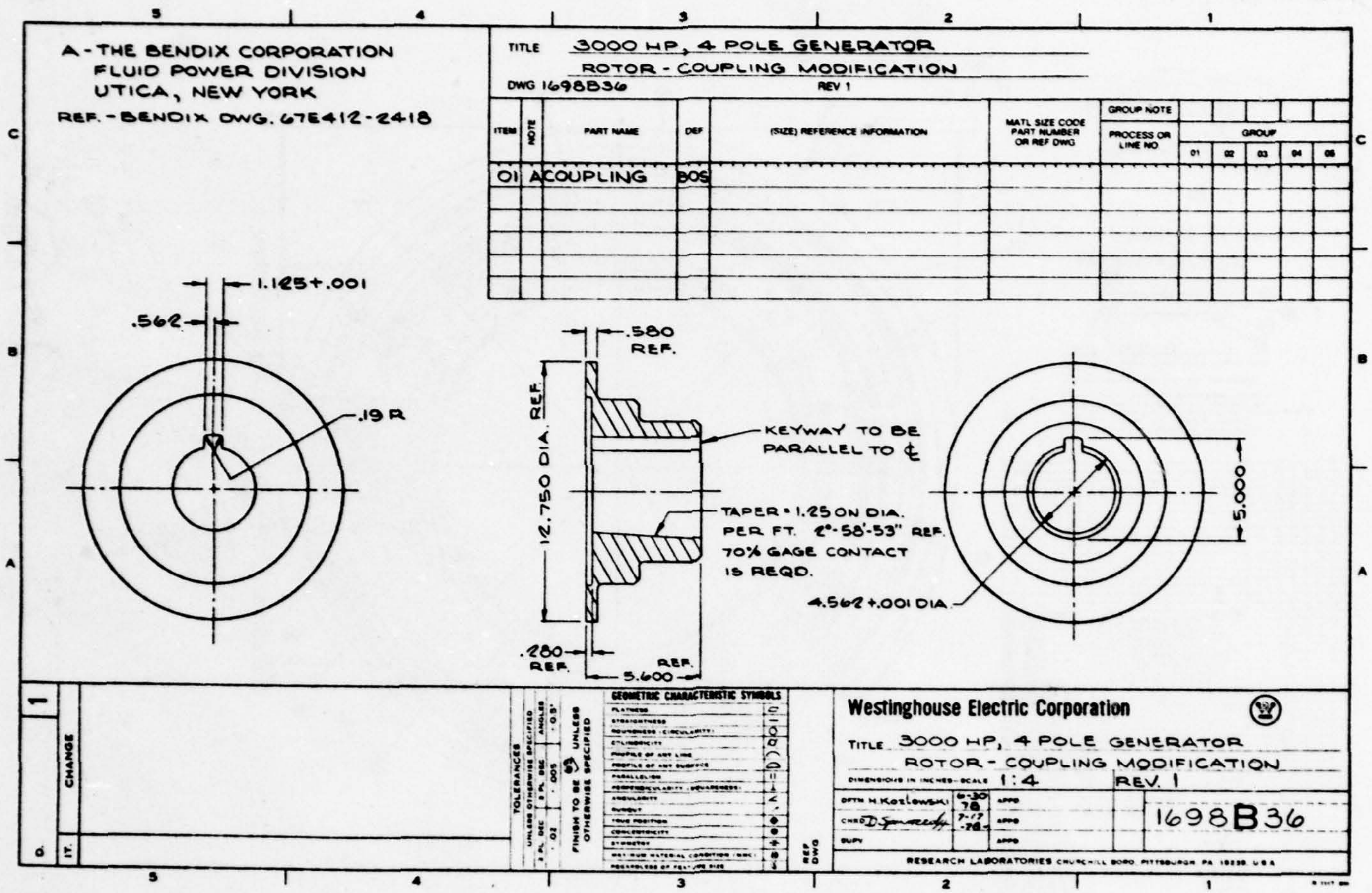
ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01		SYPHON PIPE	DWG		8521D22H03		1				
02	A	ROTATING UNION	BOS	MODEL #555 SST ROTOR #455-8			1	1			
03		SYPHON PIPE	DWG		8521D29H05			1			

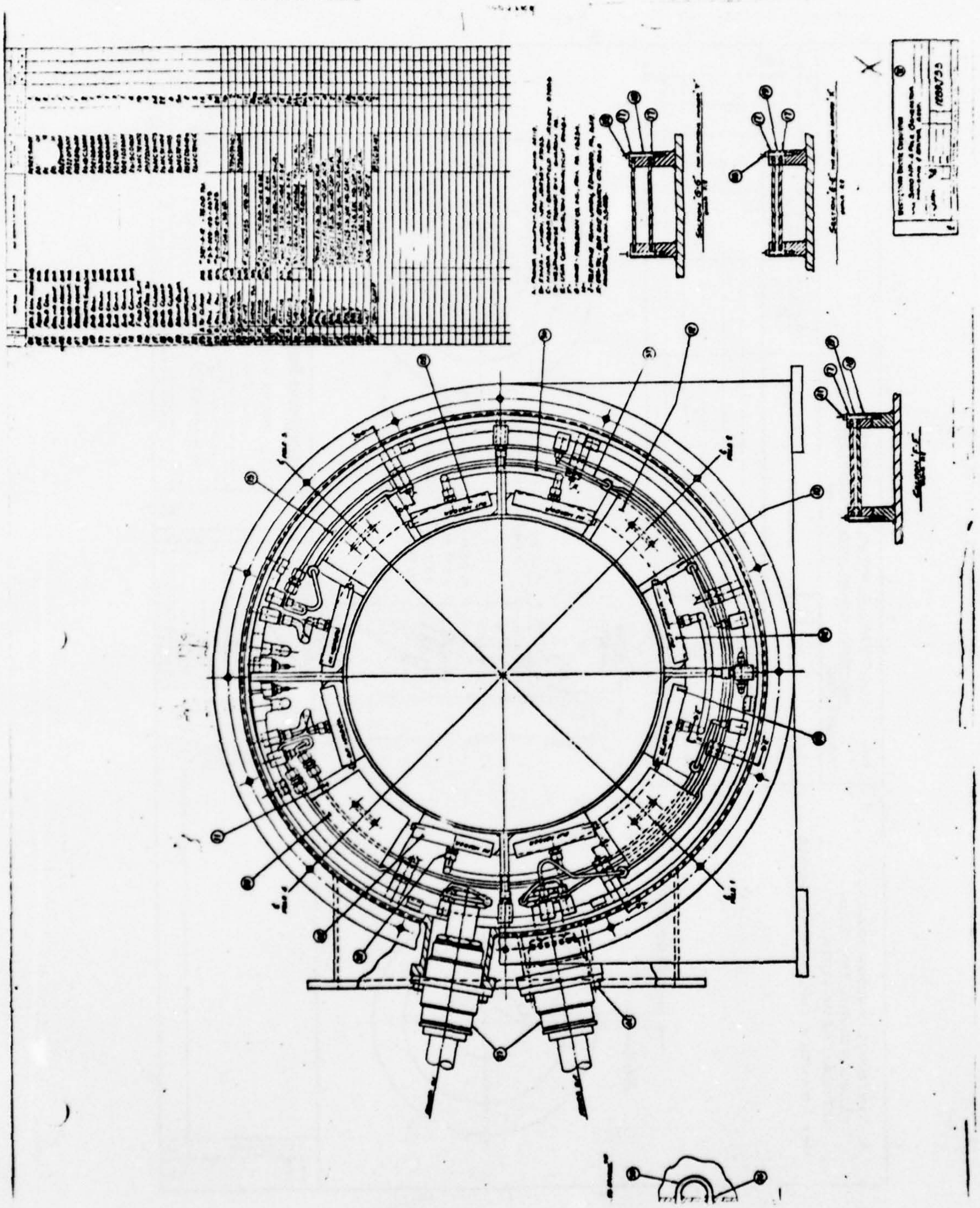
A-DEUBLIN COMPANY, NORTHBROOK, ILLINOIS

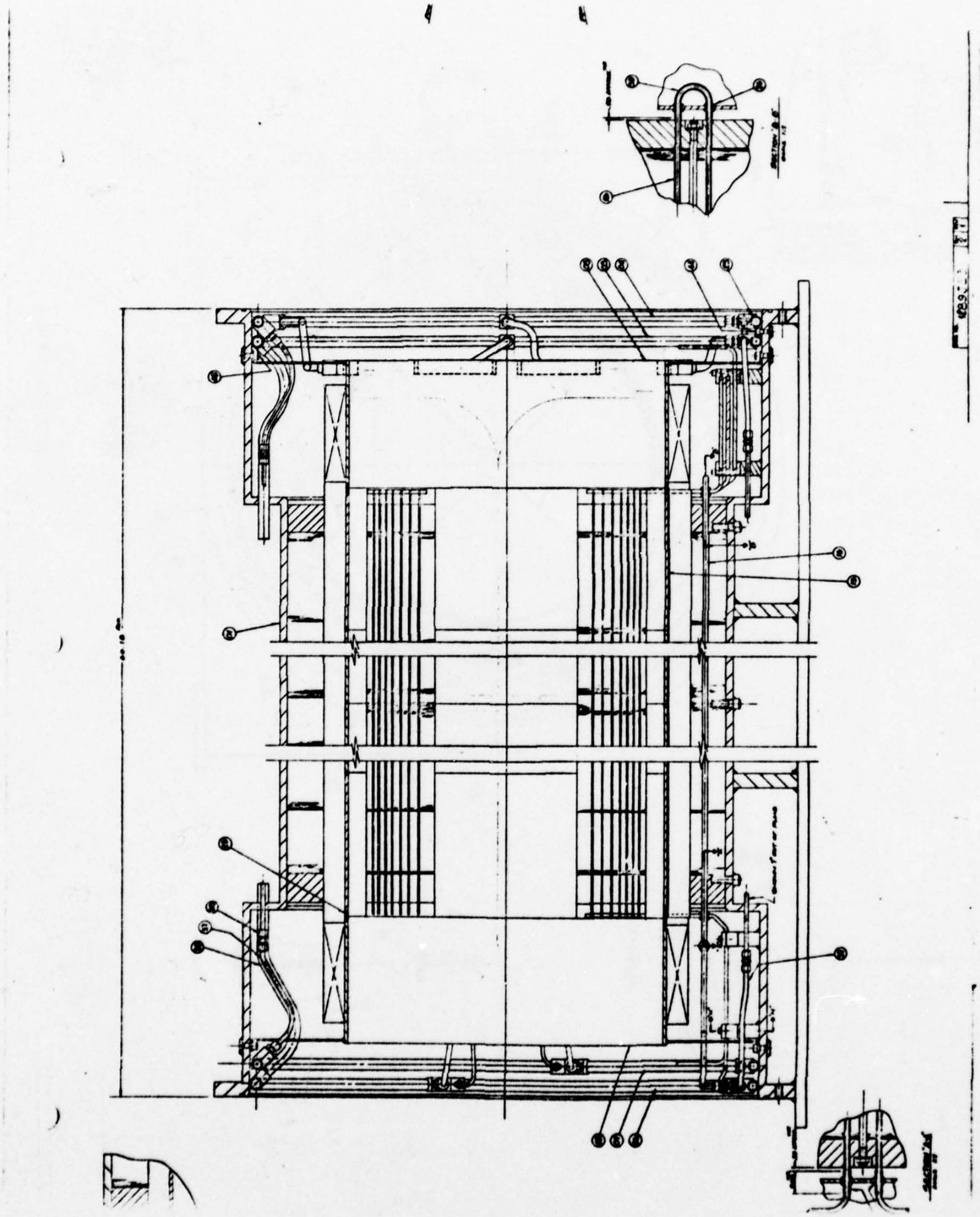
NOTE: GROUP 01 USED WITH GEN. AND GROUP 02 USED WITH MOTOR

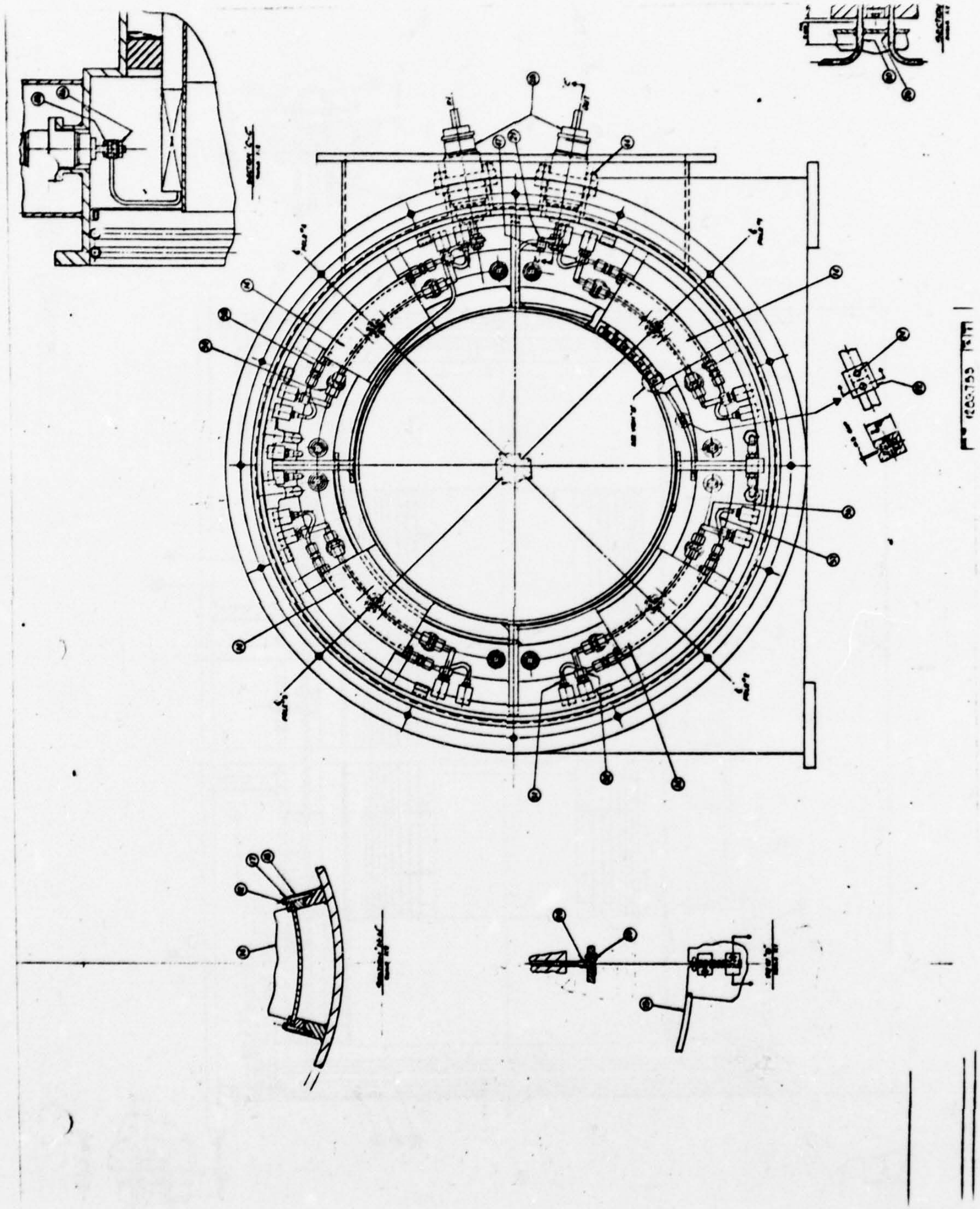


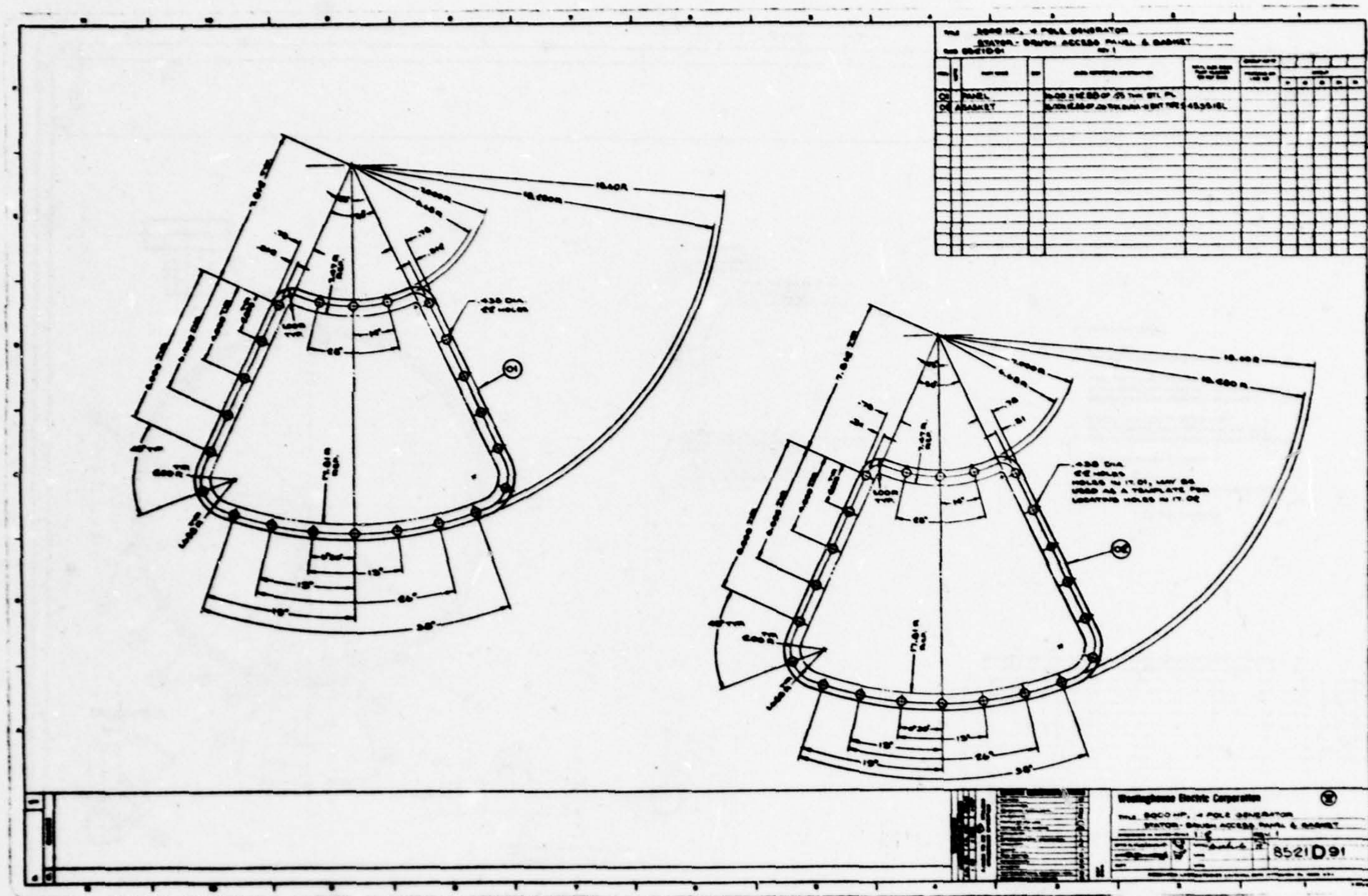
6425A42

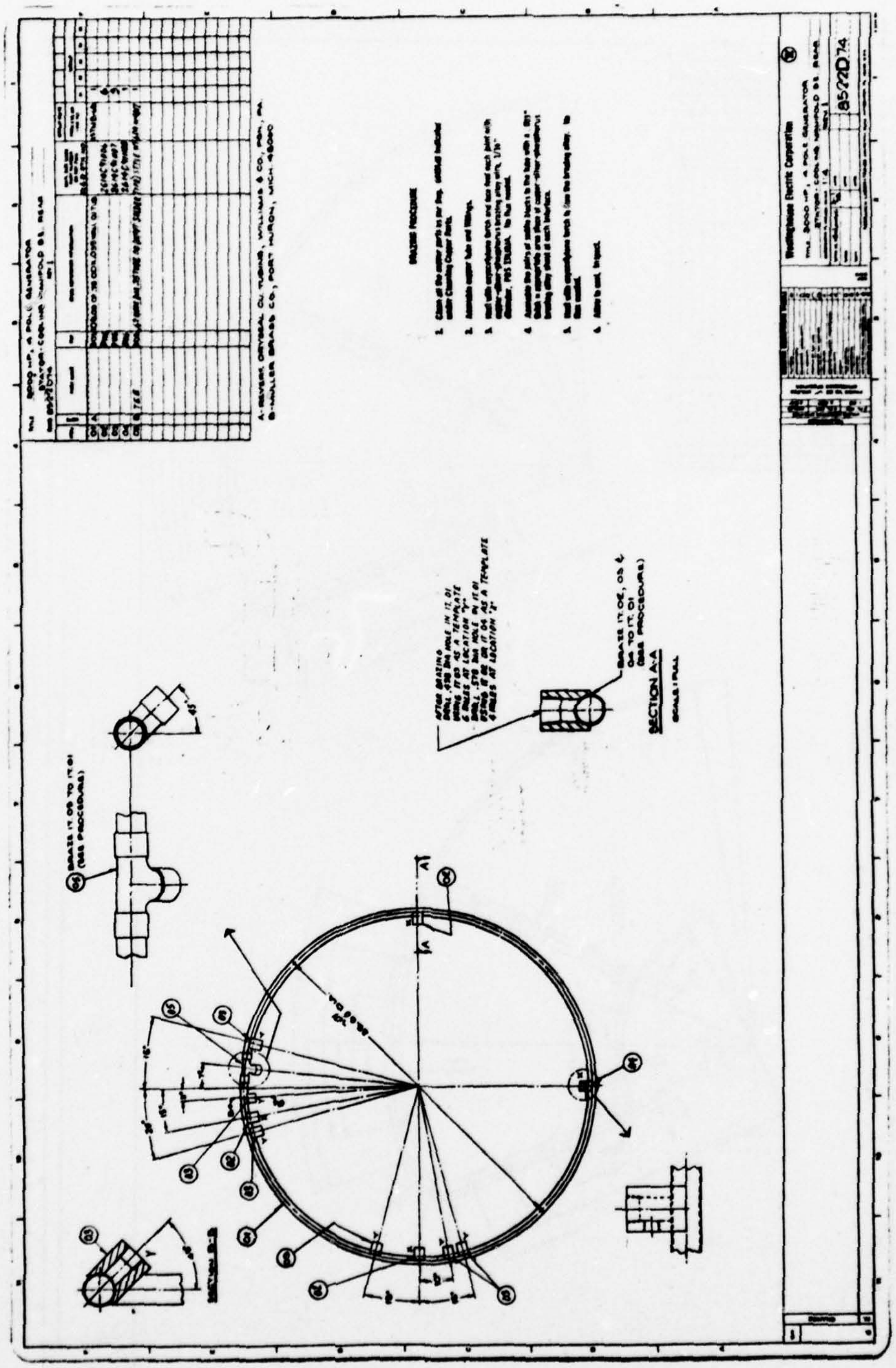

A-THE BENDIX CORPORATION
FLUID POWER DIVISION
UTICA, NEW YORK
REF.-BENDIX DWG. 67E412-2418
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - COUPLING MODIFICATION
DWG 1698B36
REV 1
ITEM
NOTE
PART NAME
DEF
(SIZE) REFERENCE INFORMATION
MATL SIZE CODE PART NUMBER OR REF DWG
GROUP NOTE
PROCESS OR LINE NO
GROUP
01 A COUPLING BOS
1.125+.001
.562
.19 R
.580 REF.
12.750 DIA. REF.
KEYWAY TO BE PARALLEL TO ℄
TAPER = 1.25 ON DIA. PER FT. 2°-58'-53" REF. 70% GAGE CONTACT IS REQD.
.280 REF.
5.600 REF.
5.000
4.562+.001 DIA.
CHANGE
TOLERANCES
UNLESS OTHERWISE SPECIFIED
FINISH TO BE UNLESS OTHERWISE SPECIFIED
GEOMETRIC CHARACTERISTIC SYMBOLS
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - COUPLING MODIFICATION
1:4
REV. 1
DFTM H. Kozlowski
1698B36
RESEARCH LABORATORIES

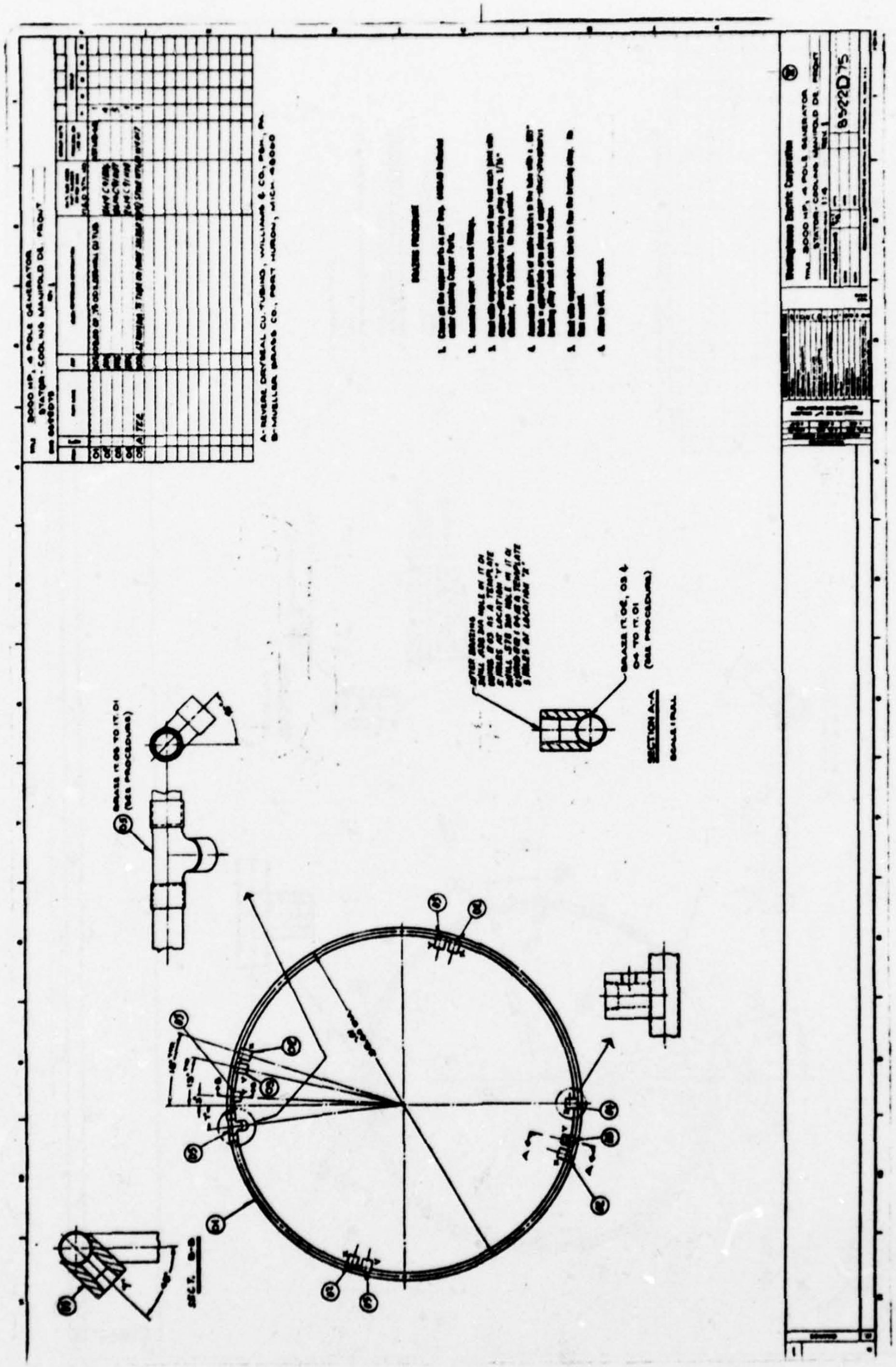


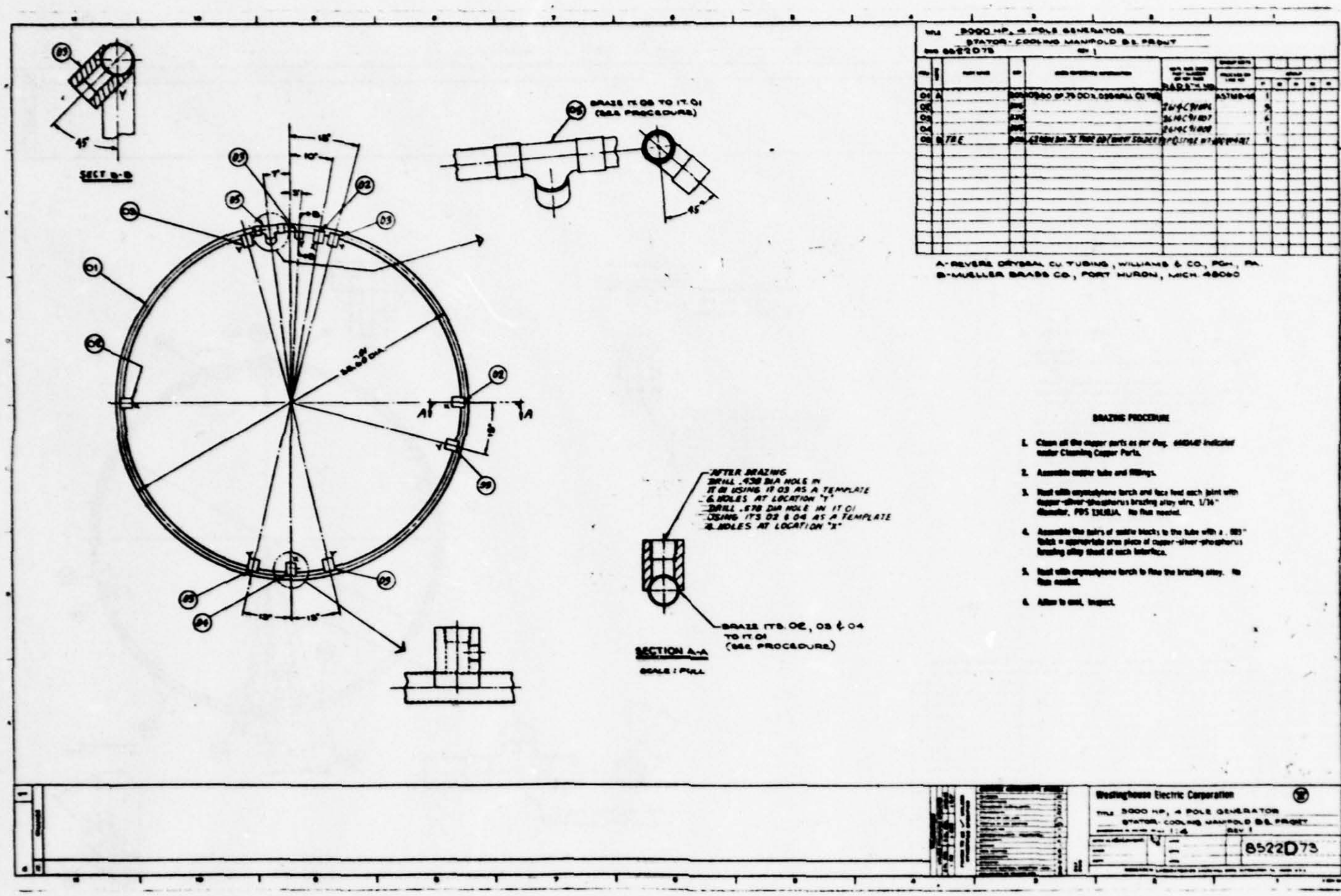


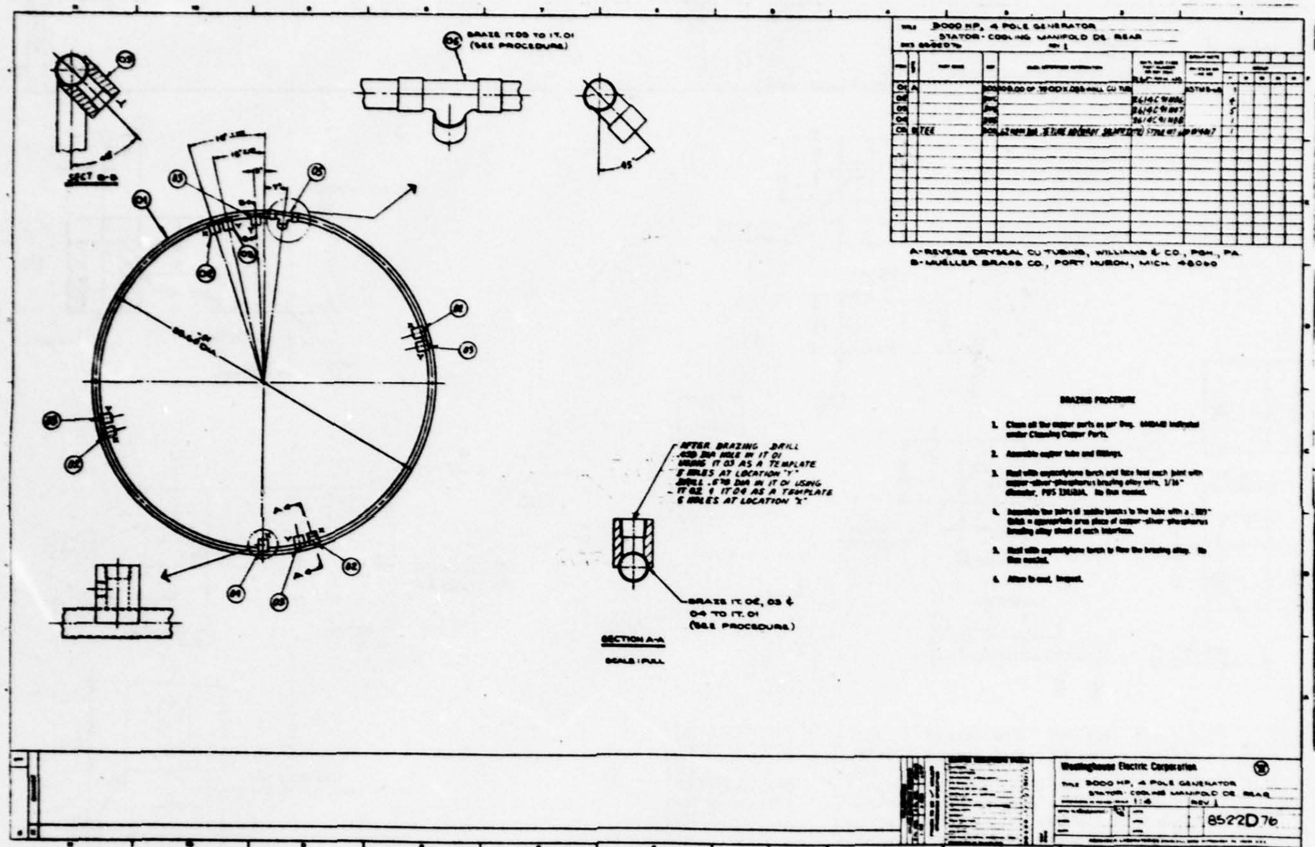



Westinghouse Electric Corporation
TITLE 5000 HP, 4 POLE GENERATOR
STATOR - BRUSH ACCESS PANEL & GASKET
8521D91
PANEL
GASKET



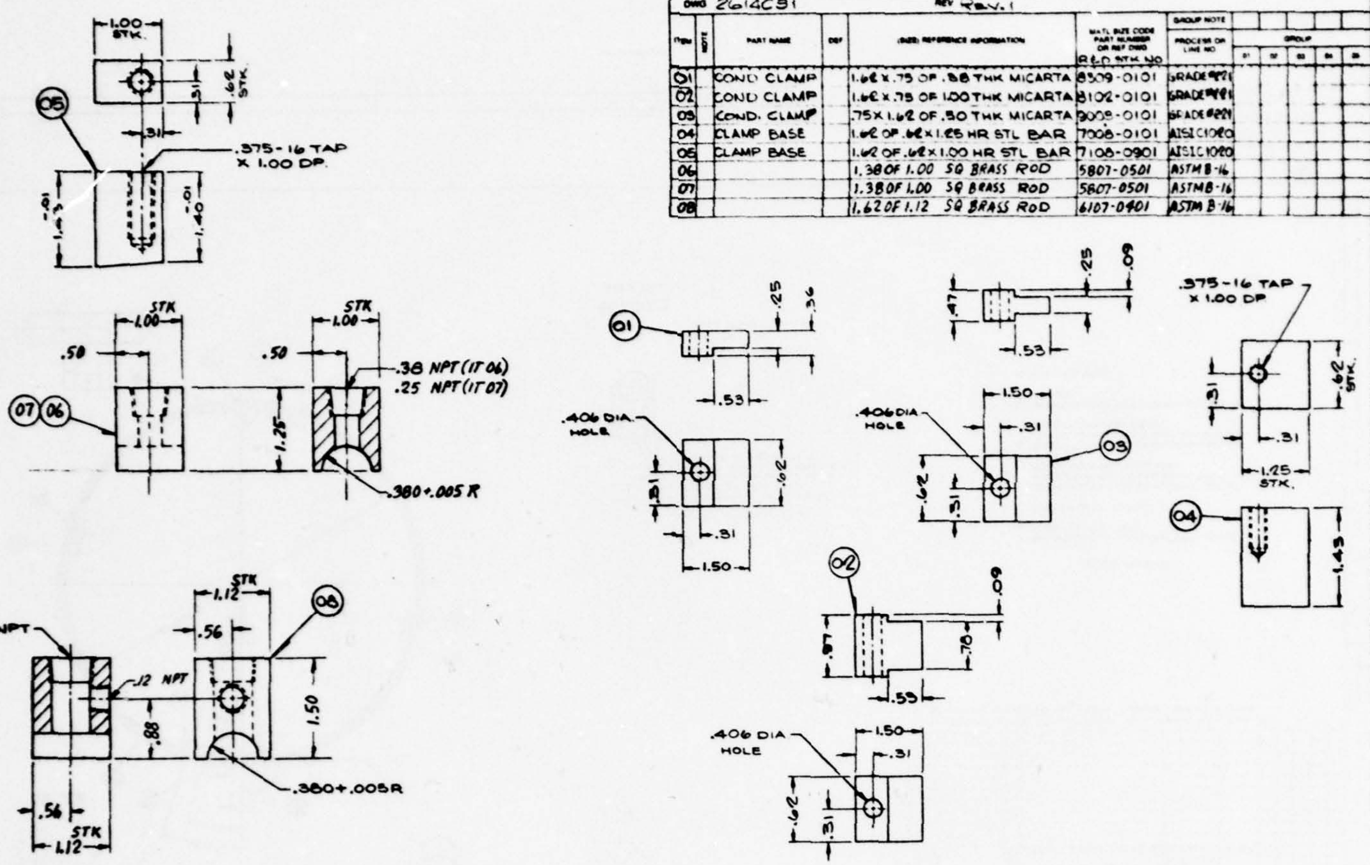

3000 HP, 4 POLE GENERATOR
STATOR - COOLING MANIFOLD DE. FRONT
A TEE
A- REVERE DRYSEAL CU. TUBING, WILLIAMS & CO., PGH., PA.
B- MUELLER BRASS CO., PORT HURON, MICH 48060
SECT. B-B
BRAZE 17.05 TO 17.01 (SEE PROCEDURE)
BRAZE 17.02, 03 & 04 TO 17.01 (SEE PROCEDURE)
SECTION A-A
SCALE: FULL
BRAZING PROCEDURE
Westinghouse Electric Corporation
1:4
REV 1
8522D75


2000 HP, 4 POLE GENERATOR
STATOR - COOLING MANIFOLD B.E. FRONT
A- REVERE OXYGEN CU TUBING, WILLIAMS & CO., PGH., PA.
B- MUELLER BRASS CO., PORT HURON, MICH. 48060
BRAZE IT 05 TO IT 01 (SEE PROCEDURE)
SECT B-B
AFTER BRAZING
DRILL .438 DIA HOLE IN IT 01 USING IT 03 AS A TEMPLATE
& HOLES AT LOCATION "Y"
DRILL .678 DIA HOLE IN IT 01 USING ITS 02 & 04 AS A TEMPLATE
& HOLES AT LOCATION "X"
BRAZE ITS 02, 03 & 04 TO IT 01 (SEE PROCEDURE)
SECTION A-A
SCALE: FULL
BRAZING PROCEDURE
2. Assemble copper tube and fittings.
6. Allow to cool, inspect.
Westinghouse Electric Corporation
2000 HP, 4 POLE GENERATOR
STATOR - COOLING MANIFOLD B.E. FRONT
8522D73

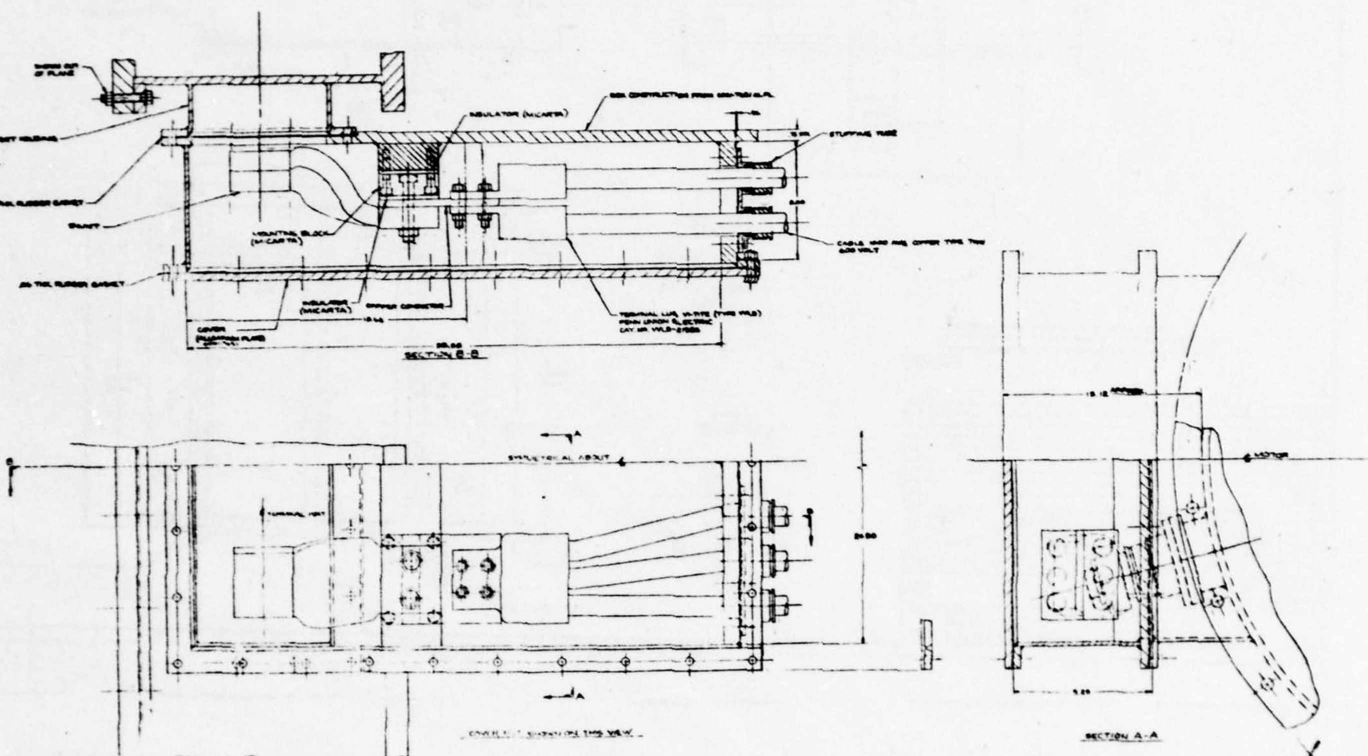

3000 HP, 4 POLE GENERATOR
STATOR - COOLING MANIFOLD DE REAR
A-REVERE DRYSEAL CU TUBING, WILLIAMS & CO., PGH., PA
B-MUELLER BRASS CO., PORT HURON, MICH. 48060
TEE
BRAZE IT 05 TO IT 01 (SEE PROCEDURE)
SECT B-B
AFTER BRAZING DRILL
HOLE IN IT 01
USING IT 03 AS A TEMPLATE
HOLES AT LOCATION "Y"
DRILL DIA IN IT 01 USING
IT 02 & IT 04 AS A TEMPLATE
HOLES AT LOCATION "Z"
BRAZE IT 02, 03 & 04 TO IT 01 (SEE PROCEDURE)
SECTION A-A
SCALE: FULL
BRAZING PROCEDURE
1. Clean all the copper parts as per ... under Cleaning Copper Parts.
2. Assemble copper tube and fittings.
6. Allow to cool. Inspect.
Westinghouse Electric Corporation
3000 HP, 4 POLE GENERATOR
STATOR - COOLING MANIFOLD DE REAR
8522D76

TITLE 3000 HP 4 POLE GENERATOR
STATOR - CLAMP DETAILS
DWG 2614C91 REV Rev. 1

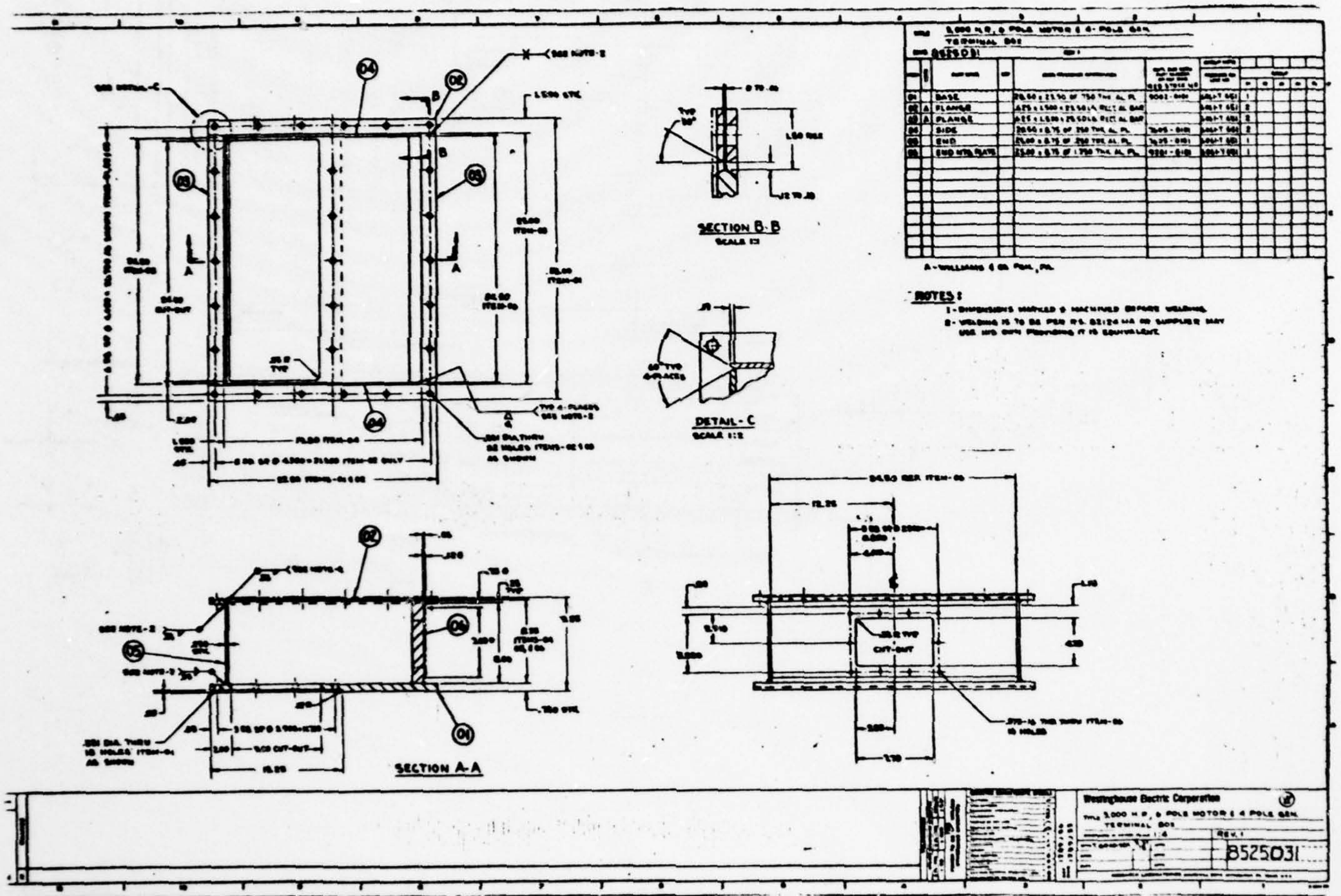
ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STK NO	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		COND CLAMP		1.62 X .75 OF .88 THK MICARTA	8309-0101	GRADE #221					
02		COND CLAMP		1.62 X .75 OF 1.00 THK MICARTA	8102-0101	GRADE #221					
03		COND. CLAMP		.75 X 1.62 OF .50 THK MICARTA	9009-0101	GRADE #221					
04		CLAMP BASE		1.62 OF .62 X 1.25 HR STL BAR	7008-0101	AISI C1020					
05		CLAMP BASE		1.62 OF .62 X 1.00 HR STL BAR	7108-0901	AISI C1020					
06				1.38 OF 1.00 SQ BRASS ROD	5807-0501	ASTM B-16					
07				1.38 OF 1.00 SQ BRASS ROD	5807-0501	ASTM B-16					
08				1.62 OF 1.12 SQ BRASS ROD	6107-0401	ASTM B-16					

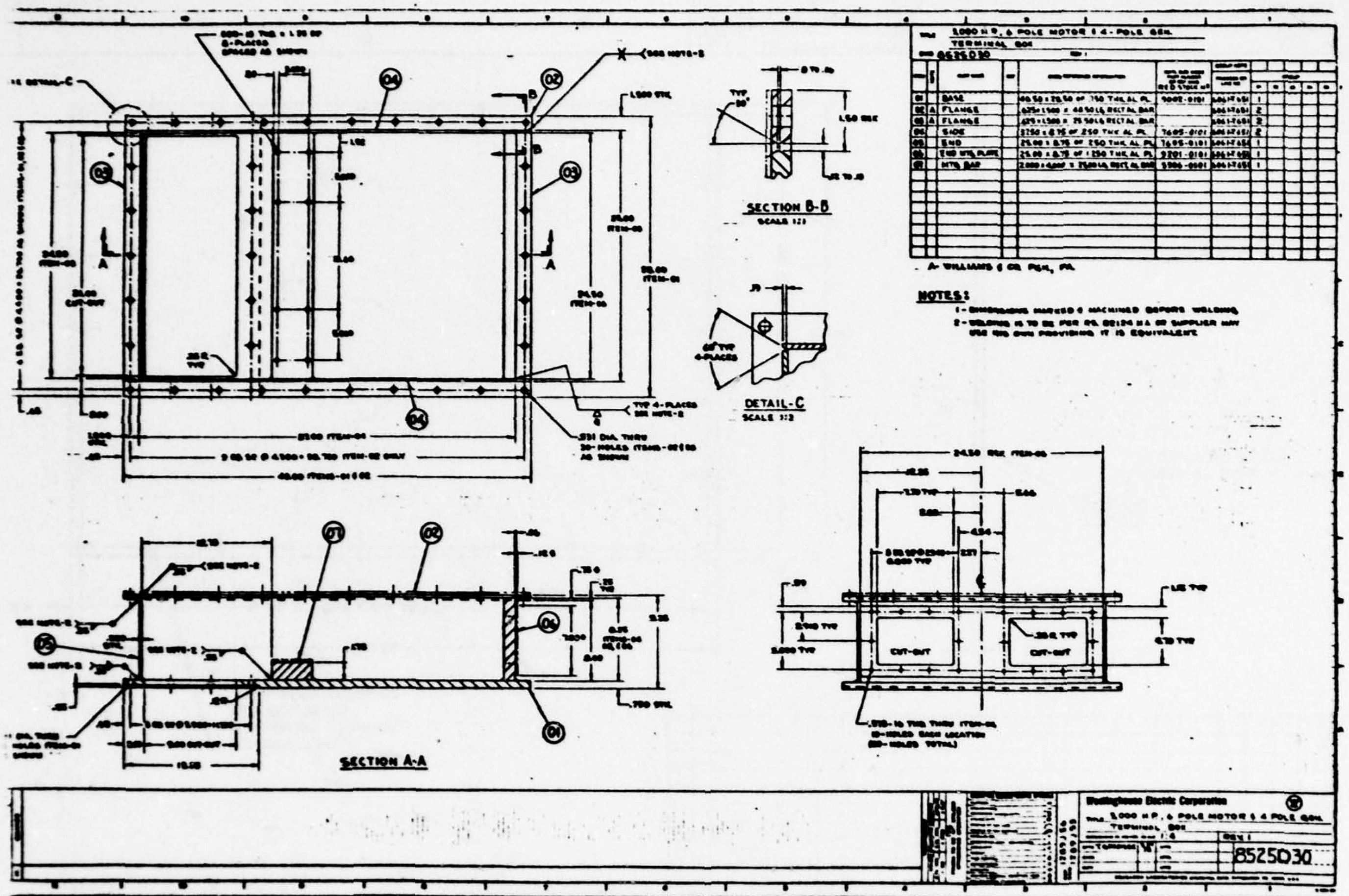


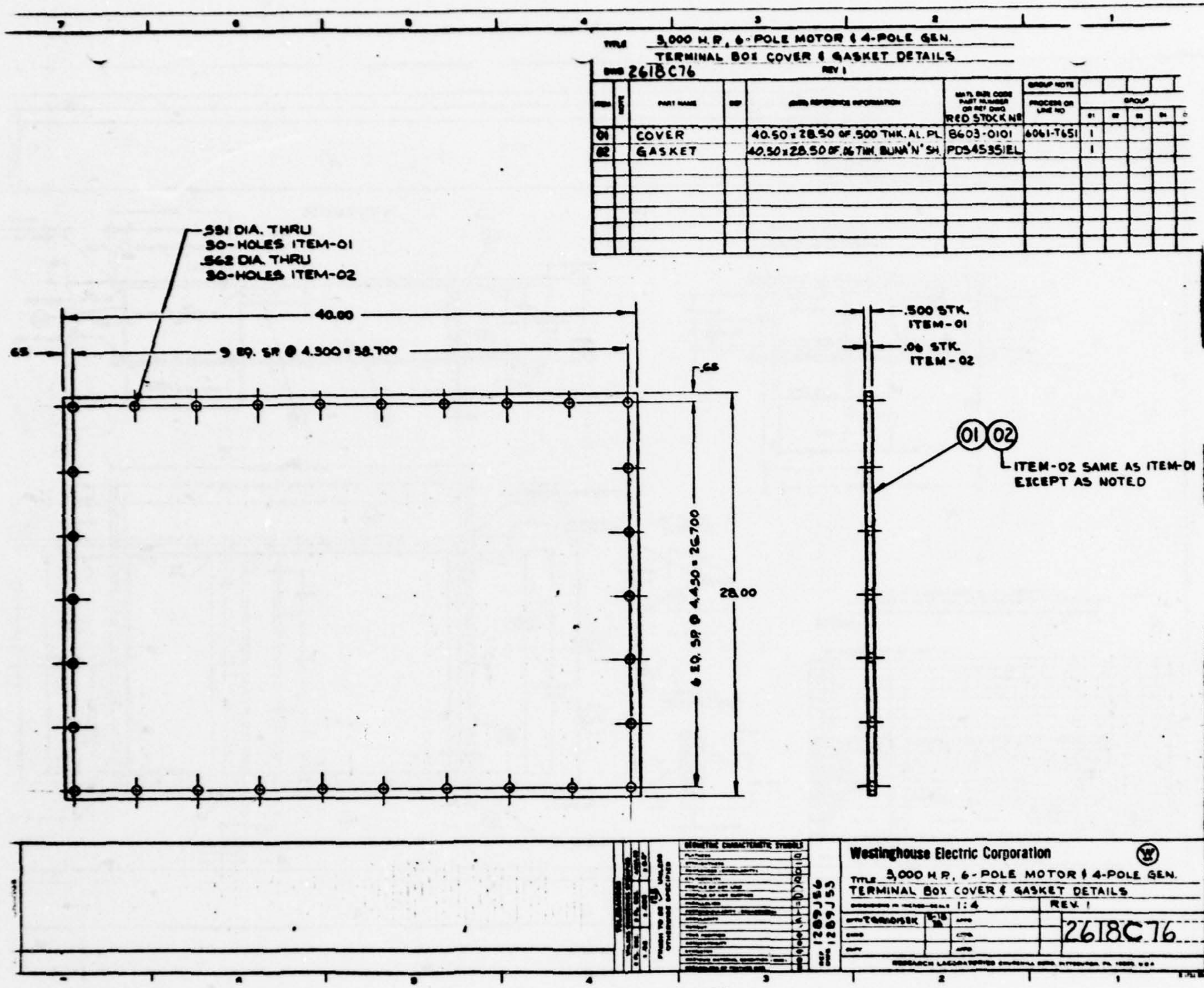
Westinghouse Electric Corporation
TITLE 3000 HP - 4 POLE GENERATOR
STATOR - CLAMP DETAILS
Rev. 1
DWN J. MARKS
2614C91
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.
CHANGE



TERMINAL BOX


SECTION B-B
DETAIL-C
SECTION A-A
NOTES:
Westinghouse Electric Corporation
B525031


SECTION B-B
DETAIL-C
SECTION A-A
CUT-OUT
BASE
FLANGE
SIDE
END
A- WILLIAMS & CO. PGH., PA.
NOTES:
Westinghouse Electric Corporation
TERMINAL BOX
8525D30

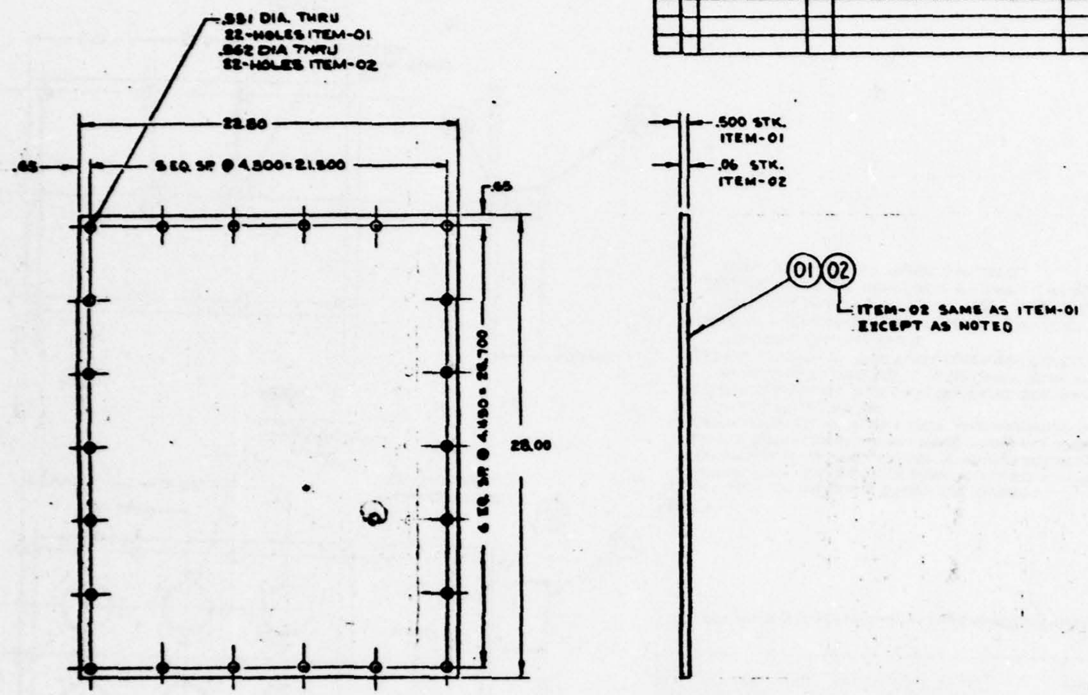


TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS
REV 1
DWG 2618C76
PART NAME
MAT'L PART CODE PART NUMBER OR REF DWG
RED STOCK NO
GROUP NOTE
PROCESS OR LINE NO
GROUP
01 COVER 40.50 x 28.50 OF .500 THK. AL. PL. 8603-0101 6061-T651 1
02 GASKET 40.50 x 28.50 OF .06 THK. BUNA 'N' SH. PDS4535IEL 1
.551 DIA. THRU
30-HOLES ITEM-01
.562 DIA. THRU
30-HOLES ITEM-02
40.00
.65
9 EQ. SP. @ 4.300 = 38.700
.65
6 EQ. SP. @ 4.450 = 26.700
28.00
.500 STK.
ITEM-01
.06 STK.
ITEM-02
01 02
ITEM-02 SAME AS ITEM-01
EXCEPT AS NOTED
Westinghouse Electric Corporation
TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS
1:4
REV. 1
2618C76
1289J56
1289J55

TITLE 3000 H.P., 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS

DWG 2618C77 REV 1

ITEM	NOTE	PART NAME	DEF	REFERENCE INFORMATION	RED STOCK NO	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		COVER		28.50 x 23.30 OF .500 THK. AL. PL.	8603-0101	6061-T651	1				
02		GASKET		28.50 x 23.30 OF .06 THK. BUNA 'N' SH.	PDS4535IEL		1				



1289J56
1289J53

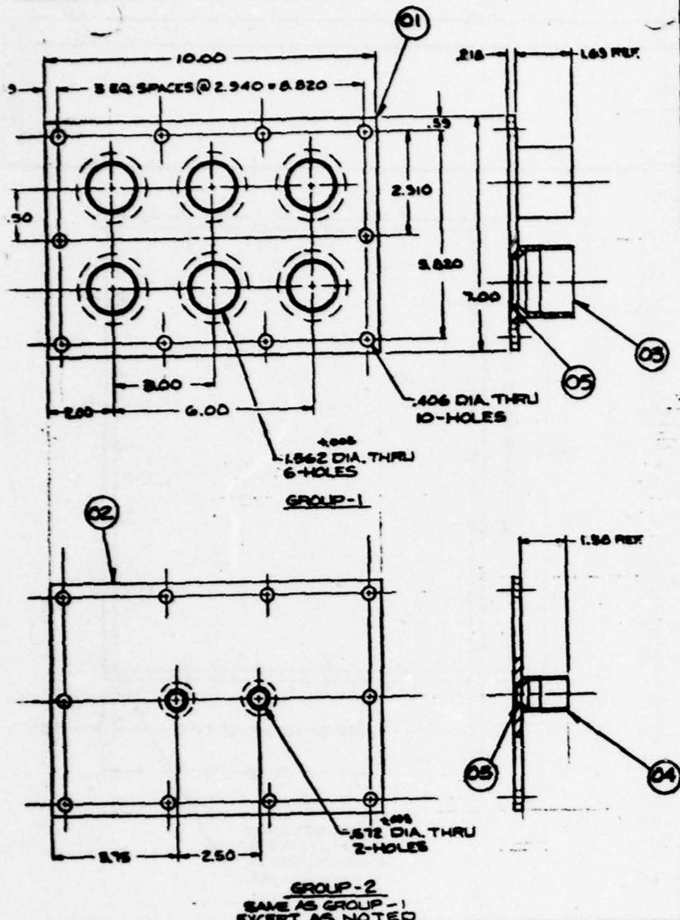
Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS

SCALE 1:4

REV 1

2618C77



TITLE 3,000 H.P. 6-POLE MOTOR & 4-POLE GEN.
STUFFING TUBE MTG. PLATES - TERM BOX

DWG 2618C72 REV. 1

ITEM	NOTE	PART NAME	DEF	PARTS REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG R&D STOCK NO.	PROCESS OR LINE NO	GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
01		MTG. PLATE		10.50 x 7.50 OF .250 THK H.R.S. PL.	8205-0101		1	-			
02		MTG. PLATE		10.50 x 7.50 OF .250 THK H.R.S. PL.	8205-0101		-	1			
03	A	STUFFING TUBE BODY		PART NR. M24235/14-041			6	-			
04	A	STUFFING TUBE BODY		PART NR. M24235/14-032			-	2			
05		FLUX PASTE			M53303AA		[illegible]	[illegible]			
06		BRAZING RING		.062 DIA. x 4.88 LG.	PDS16370CF		6	-			
07		BRAZING RING		.062 DIA. x 2.06 LG.	PDS16370CA		-	2			

A-PER MIL-S-24235/14 SHIPS (MACHINED BRASS).

NOTES:

1-METHOD OF BRAZING STUFFING TUBES:
AFTER THE PLATES HAVE BEEN DRILLED FOR THE STUFFING TUBE SIZE USED, THE FOLLOWING PROCEDURE IS RECOMMENDED FOR THE SILVER BRAZING OPERATION.
(a) ALL SURFACES MUST BE FREE FROM OIL, GREASE & SCALE PRIOR TO HEATING.
(b) PAINT NECK OF TUBE & AREA AROUND HOLE IN PLATE WITH FLUX PASTE M53303AA.
(c) PLACE BRAZING RING (.062 DIA. CROSS SECTION) OVER NECK OF TUBE & INSERT IN HOLE IN PLATE. SILVER ALLOY WIRE TO BE PER PDS16730CF.
(d) THE WEIGHT OF THE TUBE GIVES SUFFICIENT PRESSURE ON A HORIZONTAL SURFACE.
(e) HEAT UNIFORMLY BY MEANS OF OXYACETYLENE TORCH UNTIL RING MELTS & FILLETS AROUND THE TUBE & PLATE.
(f) FLUX MUST BE REMOVED BY APPLICATION OF WATER OR A WET RAG TO THE HOT TUBE & PLATE.

CHANGE

1289J56
1289J53

Westinghouse Electric Corporation

TITLE 3,000 H.P. 6-POLE MOTOR & 4-POLE GEN.
STUFFING TUBE MTG. PLATES - TERM. BOX

N.T.S. REV. 1

J. SABINO

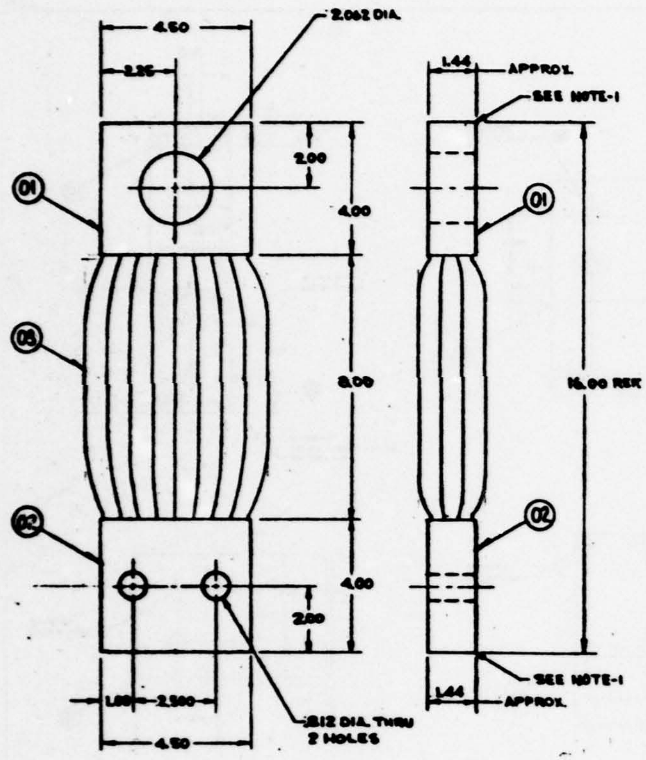
2618C72

RESEARCH LABORATORIES

TITLE 3,000 H.P. 6-POLE MOTOR & 4 POLE GENERATOR
SHUNT DETAIL - TERMINAL BOX
DWG 2618C13 REV #2

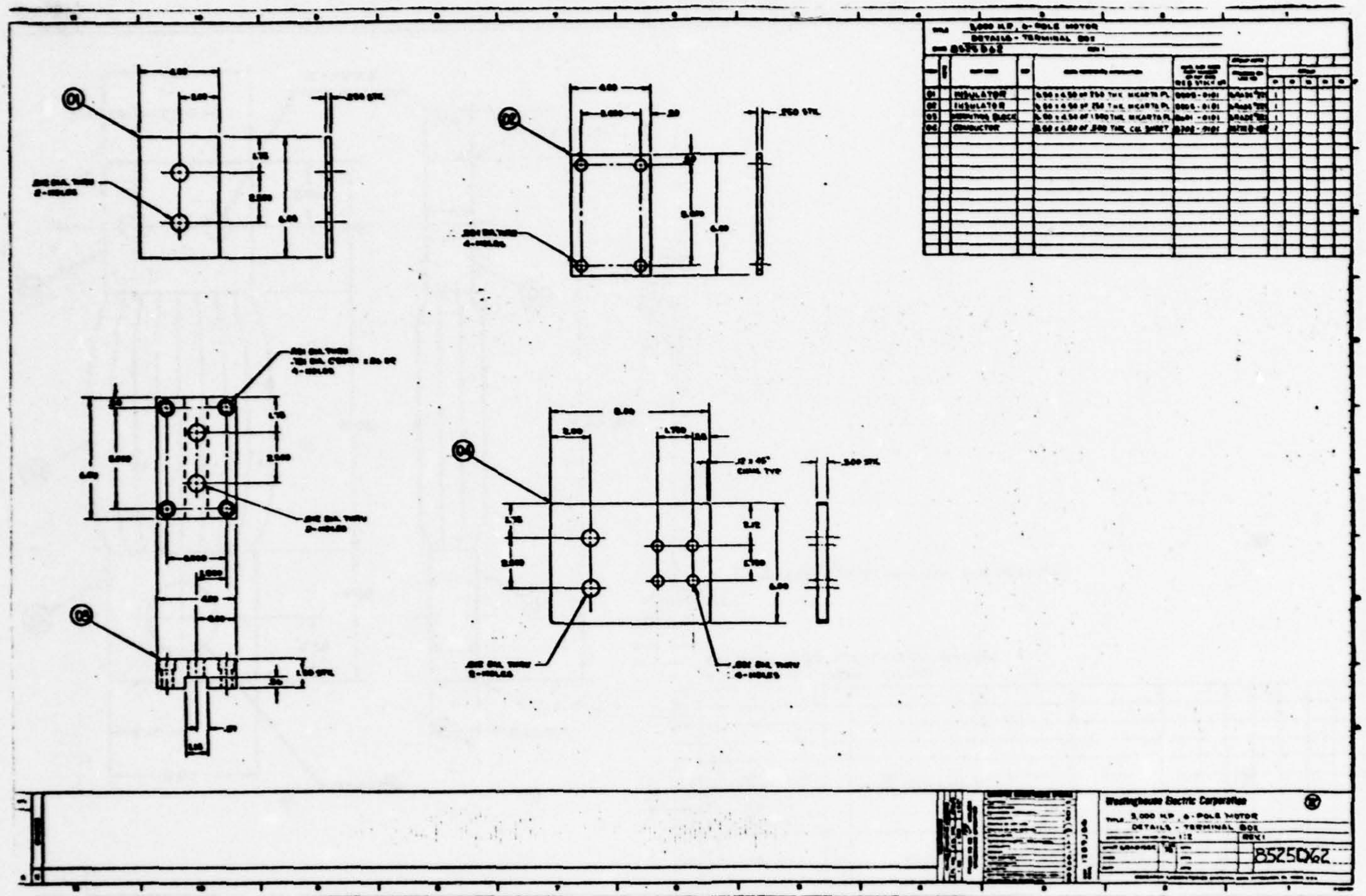
ITEM	NOTE	PART NAME	REF	(REF) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	B	FERRULE					1				
02	B	FERRULE					1				
03	A	CABLE		5400 MCM BRAID			12				

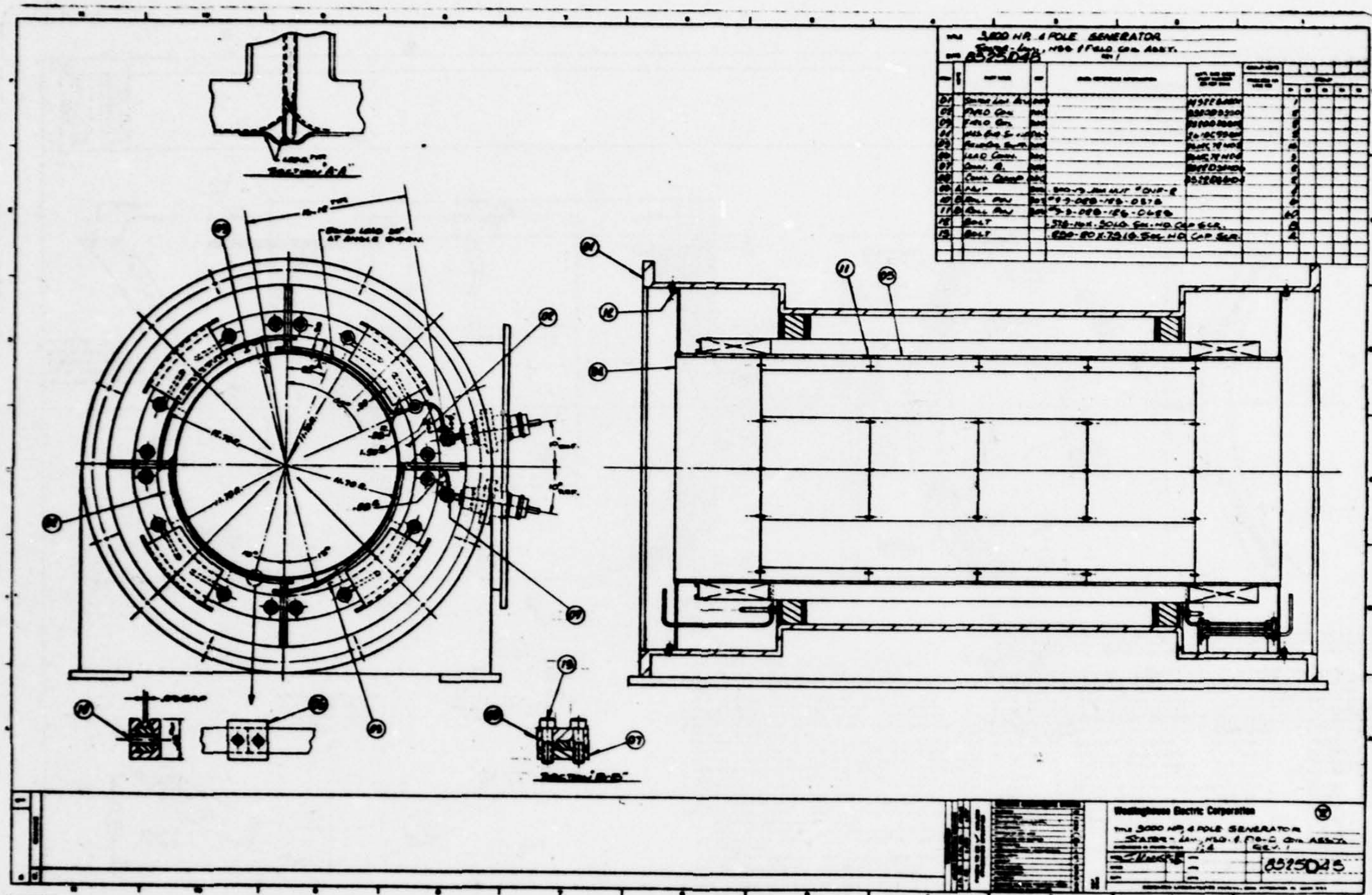
A - TELEDYNE PENN-UNION.
B - MAT'L TO BE SUPPLIED BY VENDOR.



NOTE:
1 - SILVER PLATE .0002 THK. ALL AROUND.

Westinghouse Electric Corporation
TITLE 3,000 H.P. 6-POLE MOTOR & 4 POLE GENERATOR
SHUNT DETAIL TERMINAL BOX
SCALE 1:2
REV. #2
2618C13
REVISED 2


5,000 H.P., 4-POLE MOTOR
DETAILS - TERMINAL BOX
01 INSULATOR 6.50 x 4.50 of .250 THK. MICARTA PL.
02 INSULATOR 6.50 x 4.50 of .250 THK. MICARTA PL.
03 MOUNTING BLOCK 6.50 x 4.50 of 1.500 THK. MICARTA PL.
04 CONDUCTOR 6.50 x 6.00 of .500 THK. CU. SHEET
Westinghouse Electric Corporation
TITLE 5,000 H.P., 4-POLE MOTOR
DETAILS - TERMINAL BOX
1:2
B525D62



3000 HP, 4 POLE GENERATOR
Westinghouse Electric Corporation
8525D45

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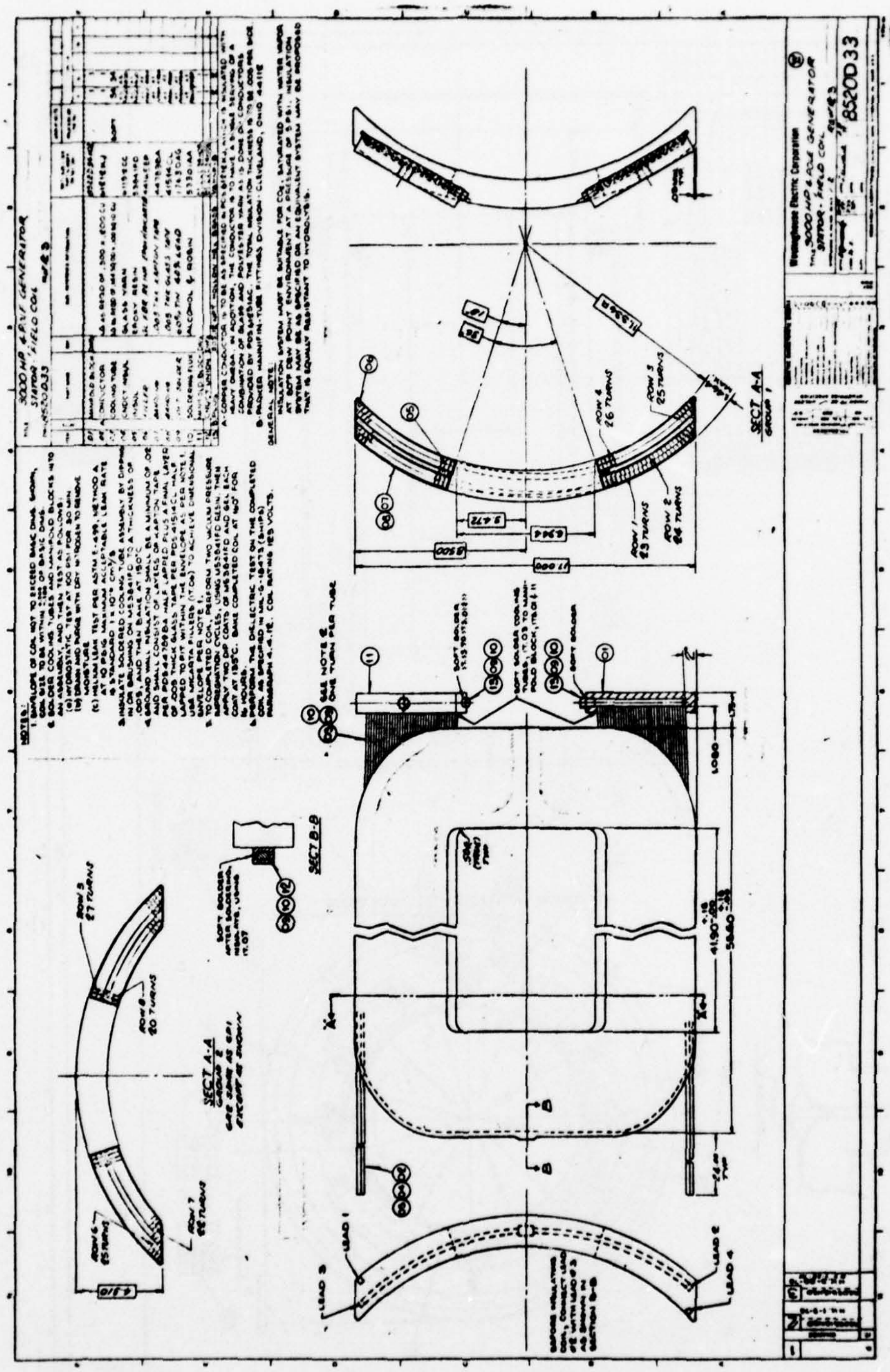
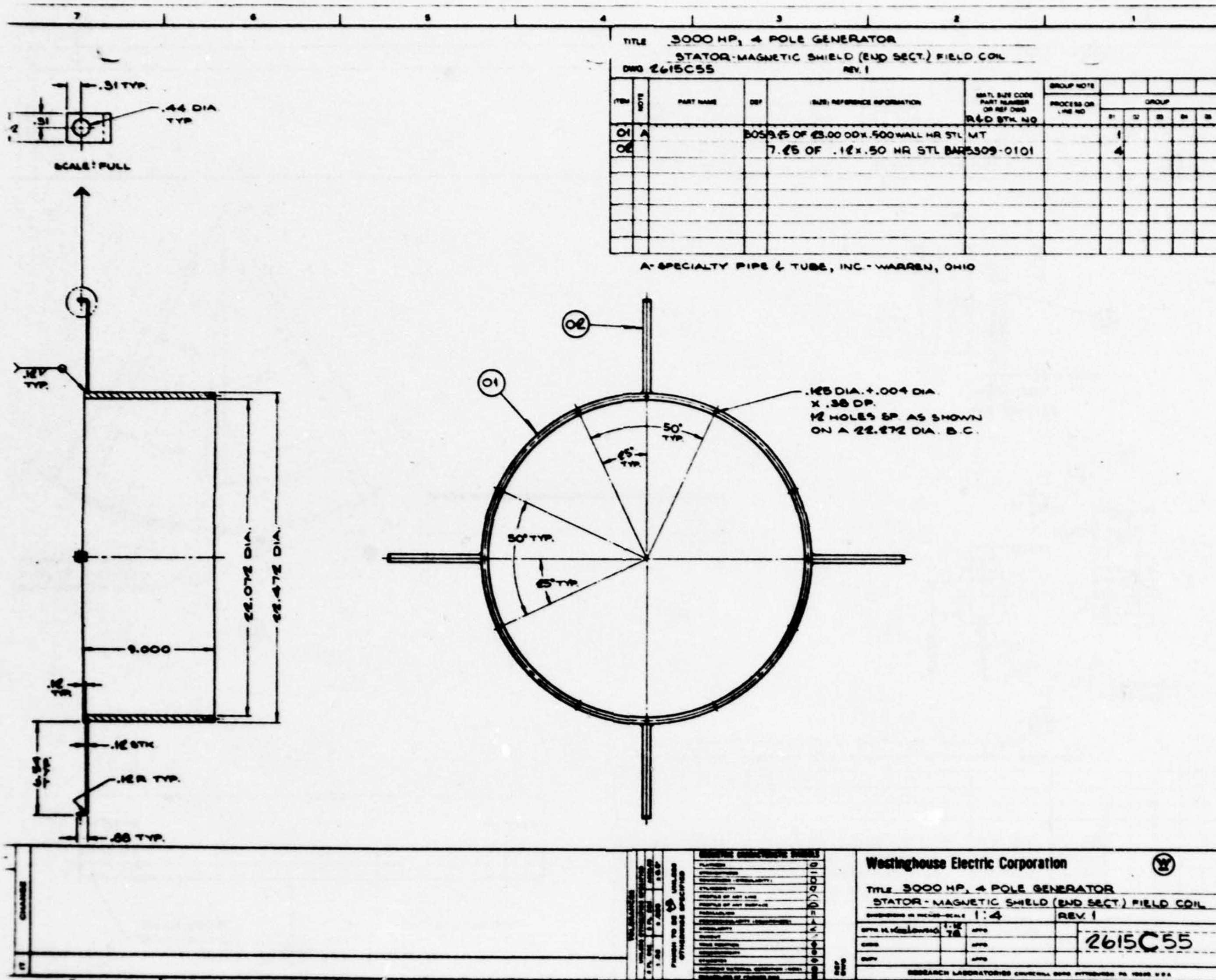
FROM COPY FURNISHED TO DDC



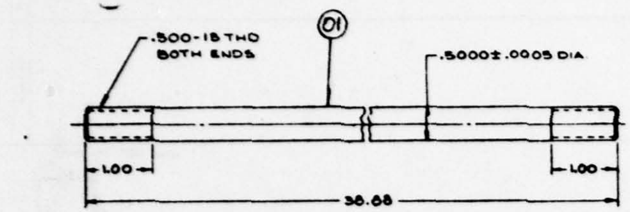


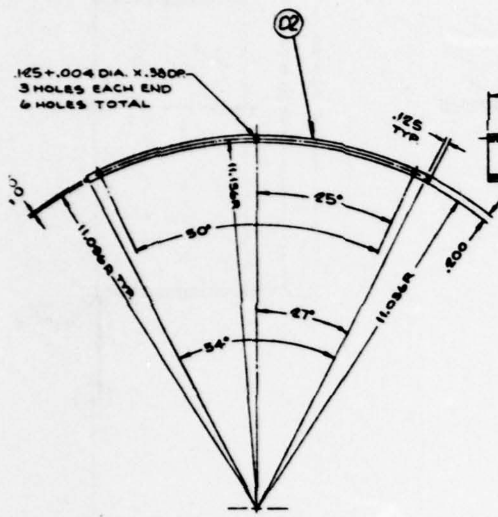
ITEM	NOTE	PART NAME	DEF	SIZE; REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP
01	A			3059.25 OF 23.00 OD X .500 WALL HR STL	MT	1
02				7.25 OF .12 X .50 HR STL BAR	5309-0101	4

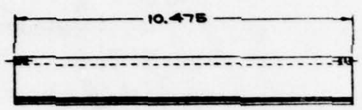
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - FIELD COIL SPRT & LAMINATION RET ROD DETS
DWG 2614C72 REV 1

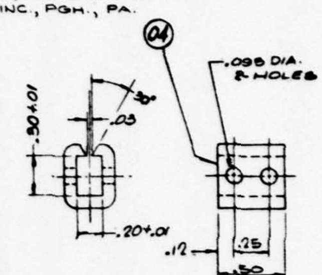
ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STK NO	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	LAM ROD		40.00 OF 5.000 DIA STL		AISI 1045					
02		FIELD COIL SPRT		11.00 x 10.62 OF .25 THK SST	8305-0101	TYPE 304					
03		BACK UP COLLAR		1.62 x .38 OF .25 THK CU SH	7705-0101	ASTM B-152					
04		LEAD CONN.		1.12 x .62 OF .094 THK CU SH	9406-0101	ASTM B-152					

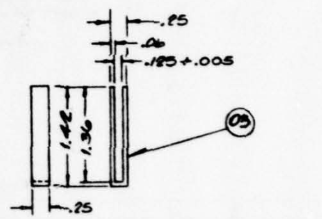
A - DRAWN, GROUND & POLISHED, ACCURACY ROUNDS
JOSEPH T. RYERSON & SON, INC., PGH., PA.







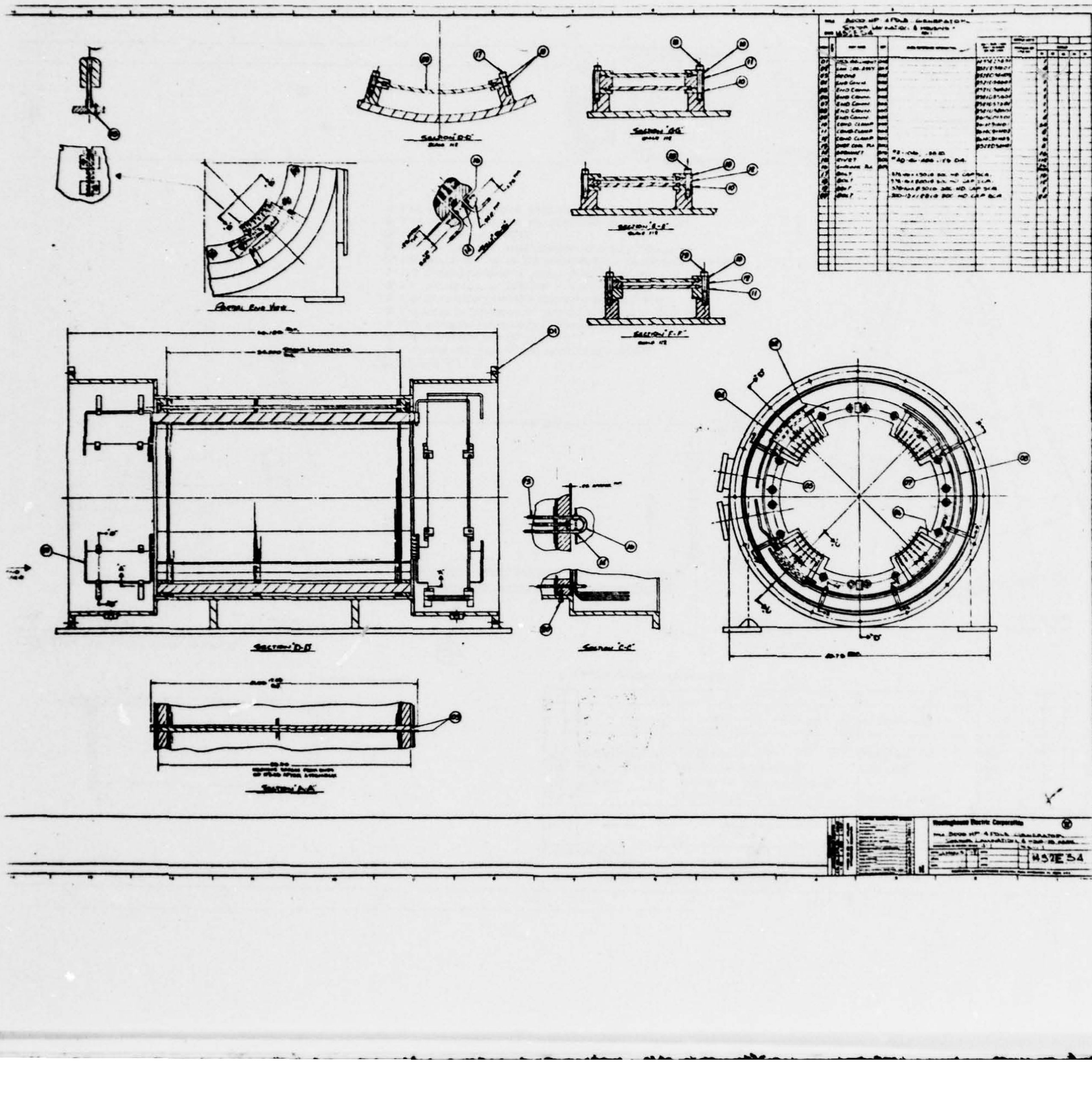




CHANGE

TOLERANCES UNLESS OTHERWISE SPECIFIED
FINISH TO BE √ UNLESS OTHERWISE SPECIFIED
GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - FIELD COIL SPRT & LAMINATION RET ROD DETS
DIMENSIONS IN INCHES - SCALE
REV 1
2614C72
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA

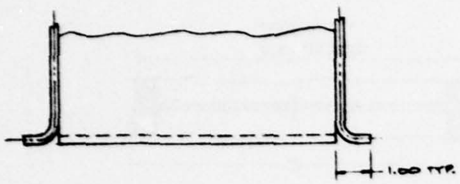


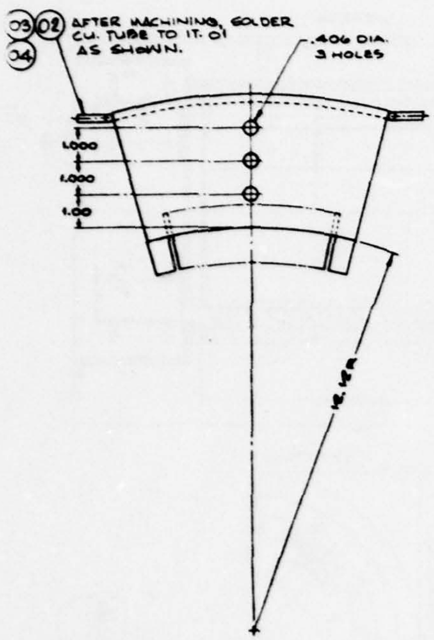
Westinghouse Electric Corporation
H57E54

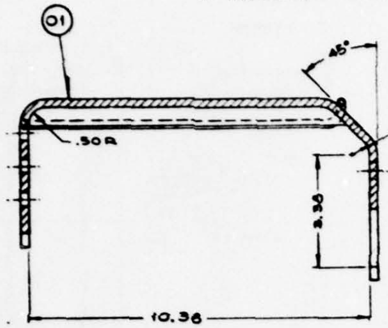
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION TO BRUSH SHUNT
DWG 2615C01 REV 1

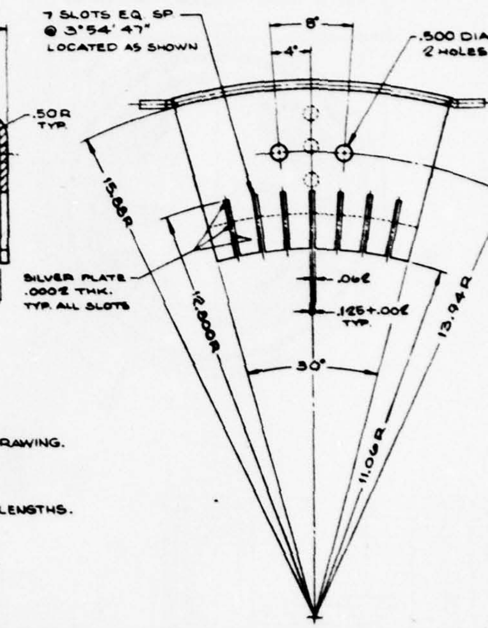
ITEM	NOTE	PART NAME	DEF	REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO
01	A			ROLL FROM .25 THK CU PL	ASTM B152-77	
02		TUBE		33.00 OF .2500 X .032 WA. CU		
03		SOFT SOLDER		60% TIN, 40% LEAD	17630AS	
04		SOLDERING FLUX		ALCOHOL RESIN	53301AA	

A - ALTERNATE 15406CB.









ORDERING DATA

3.1.1. FOR QUANTITY, SEE PURCHASE ORDER.
3.1.2. COPPER UNS No. C10100.
3.1.3. TEMPER H03-THREE QUARTERS HARD.
3.1.4. FOR DIMENSIONS, SEE DETAILS PER THIS DRAWING.
3.1.5. ROUNDED CORNER EDGES ARE REQUIRED.
3.1.6. RESISTIVITY TESTING IS REQUIRED.
3.1.7. EMBRITTLEMENT TESTING IS REQUIRED.
3.1.8. MATERIAL IS TO BE FURNISHED IN STRAIGHT LENGTHS.
3.1.9. SEE DETAIL, THIS DRAWING FOR LENGTH.
3.1.10. NOT APPLICABLE.
3.1.11. CERTIFICATION OF TESTING IS REQUIRED.
3.1.12. TEST REPORTS ARE NOT REQUIRED.

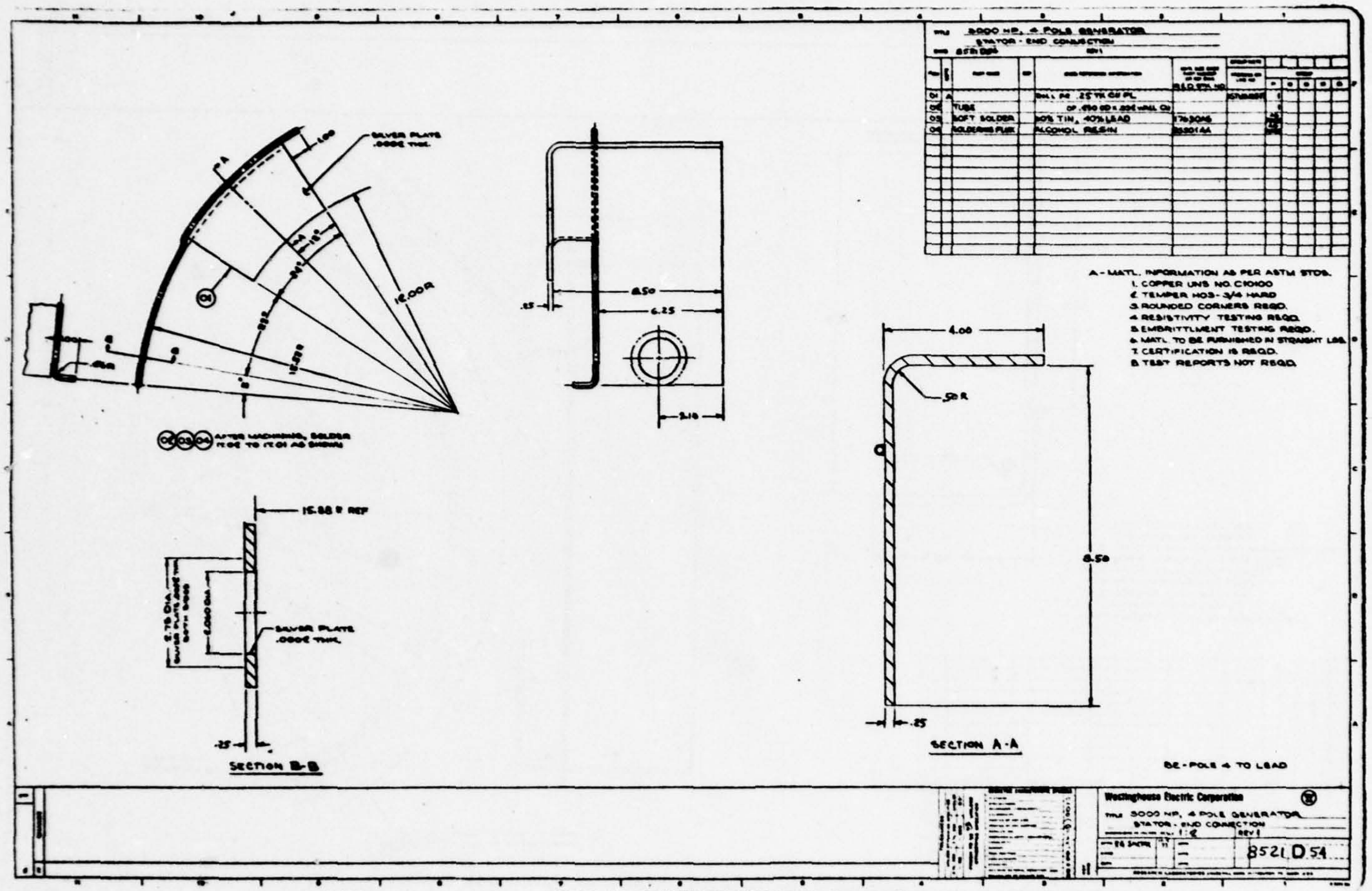
CHANGE

FINISH TO BE UNLESS OTHERWISE SPECIFIED

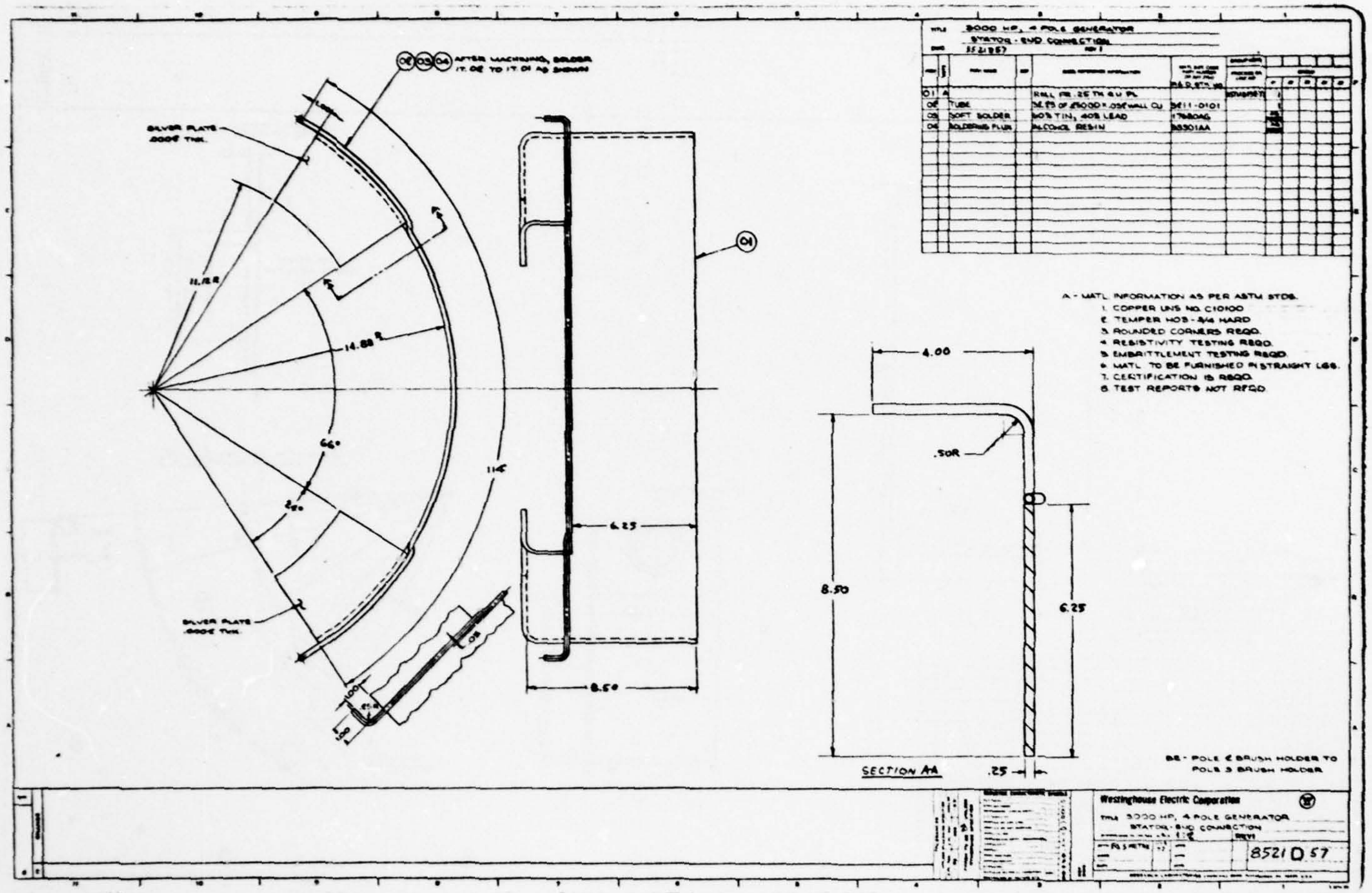
Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
STATOR-END CONNECTION TO BRUSH SHUNT
DIMENSIONS IN INCHES—SCALE 1:2 REV. 1
2615C01

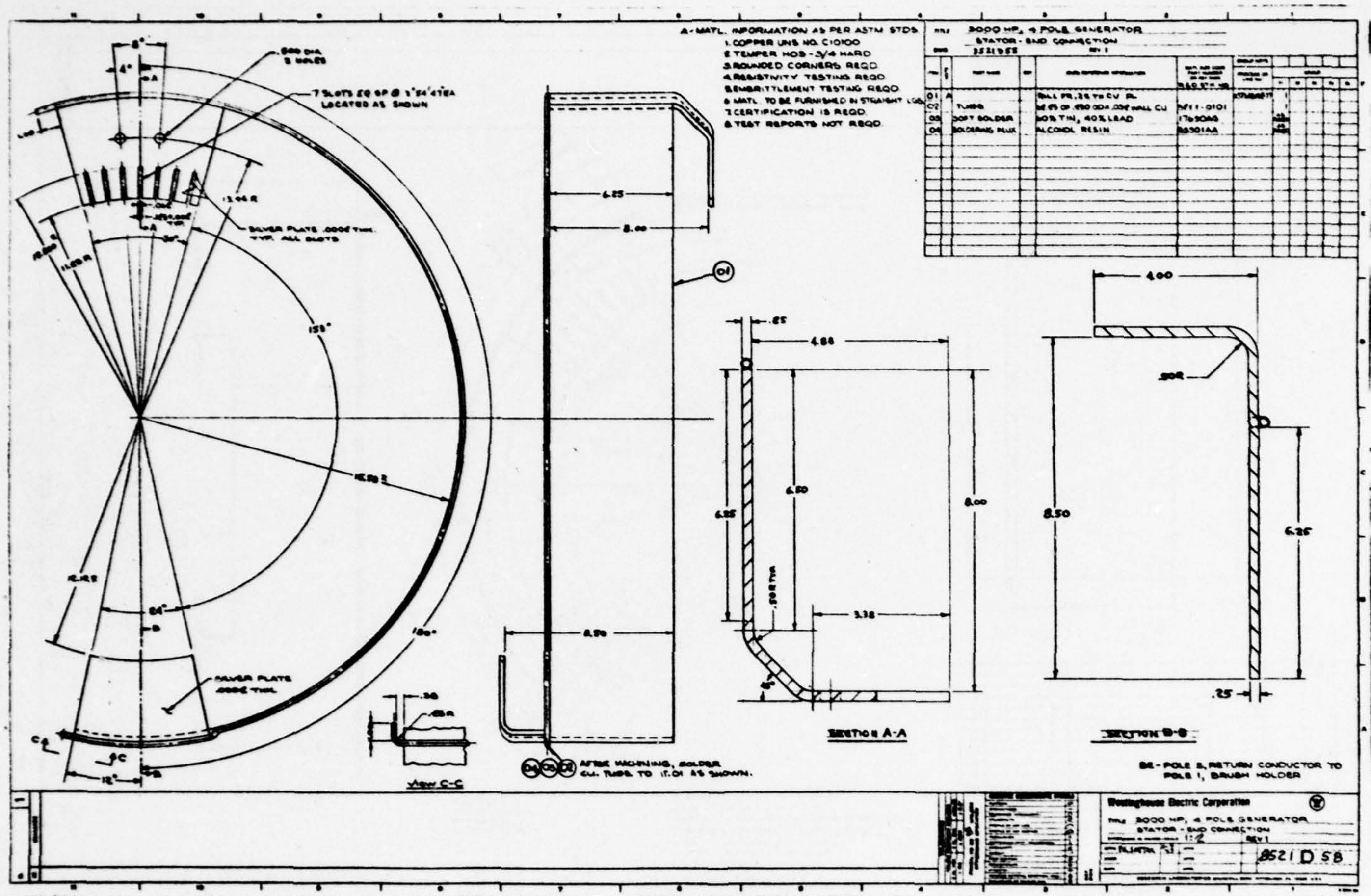
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

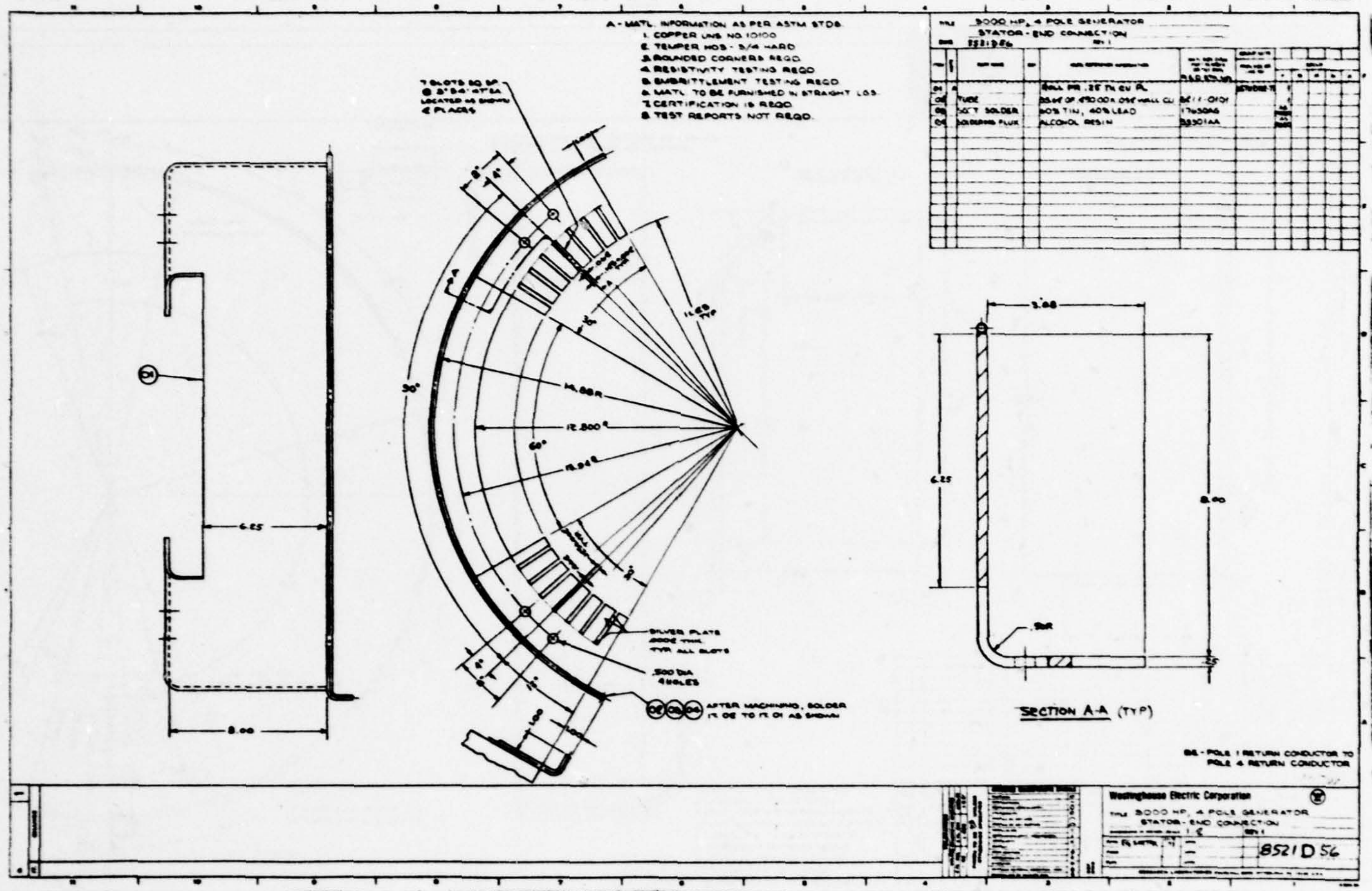


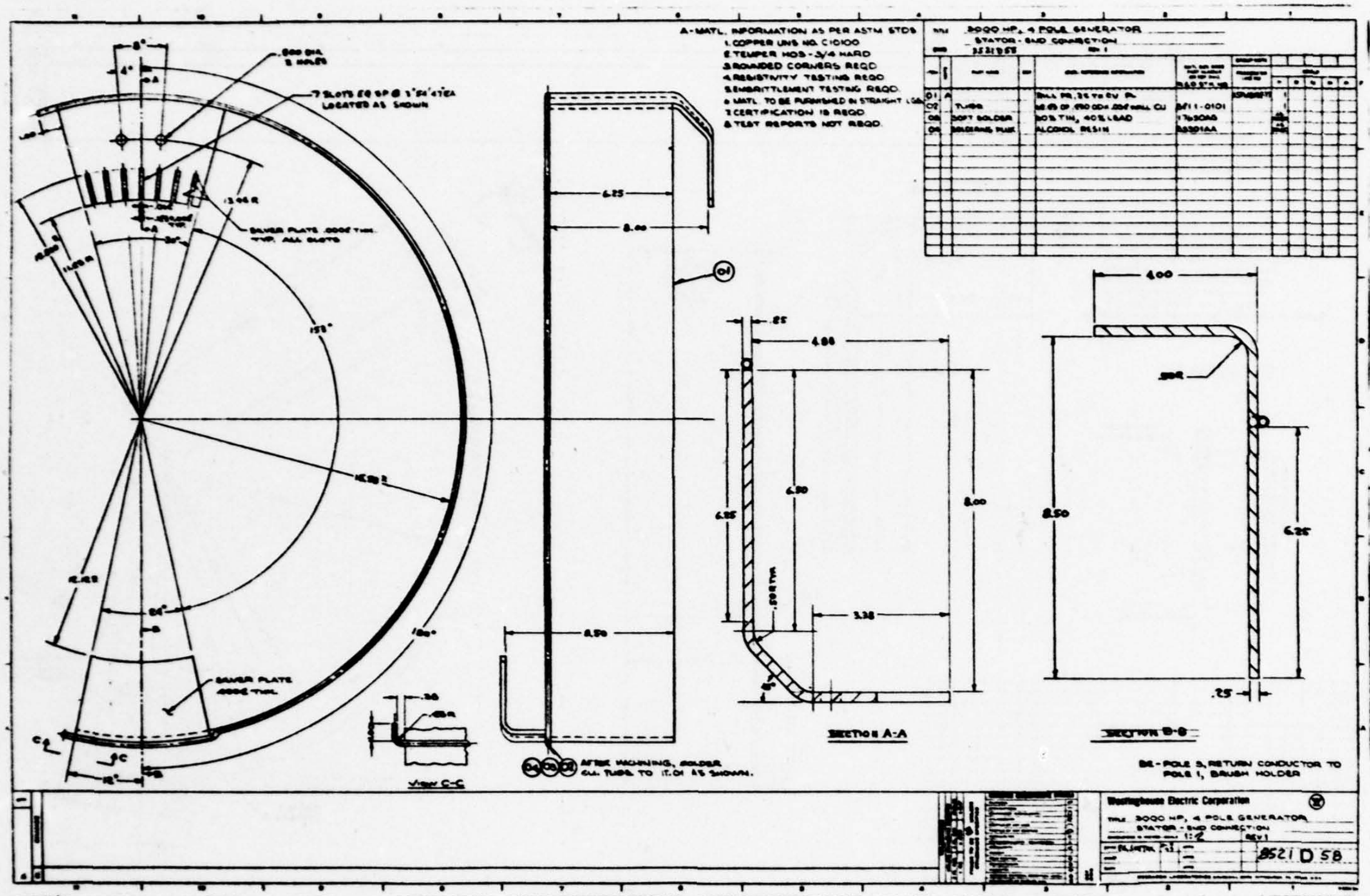
5000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
01 A SHT. PL .25 TK CU PL
02 TUBE .190 OD x .026 WALL CU
03 SOFT SOLDER 60% TIN, 40% LEAD 1763046
04 SOLDERING FLUX ALCOHOL RESIN 2530144
A - MATL. INFORMATION AS PER ASTM STDS.
1. COPPER UNS NO. C10100
2. TEMPER H03 - 3/4 HARD
3. ROUNDED CORNERS REQD.
4. RESISTIVITY TESTING REQD.
5. EMBRITTLEMENT TESTING REQD.
6. MATL. TO BE FURNISHED IN STRAIGHT LGS.
7. CERTIFICATION IS REQD.
8. TEST REPORTS NOT REQD.
SILVER PLATE .0002 THK.
16.00 R
AFTER MACHINING, SOLDER 02 TO 01 AS SHOWN
8.50
6.25
3.10
.25
4.00
.50 R
15.88 R REF
2.75 DIA.
2.000 DIA.
SILVER PLATE .0002 THK.
SECTION B-B
SECTION A-A
BE - POLE 4 TO LEAD
Westinghouse Electric Corporation
5000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
8521 D 54

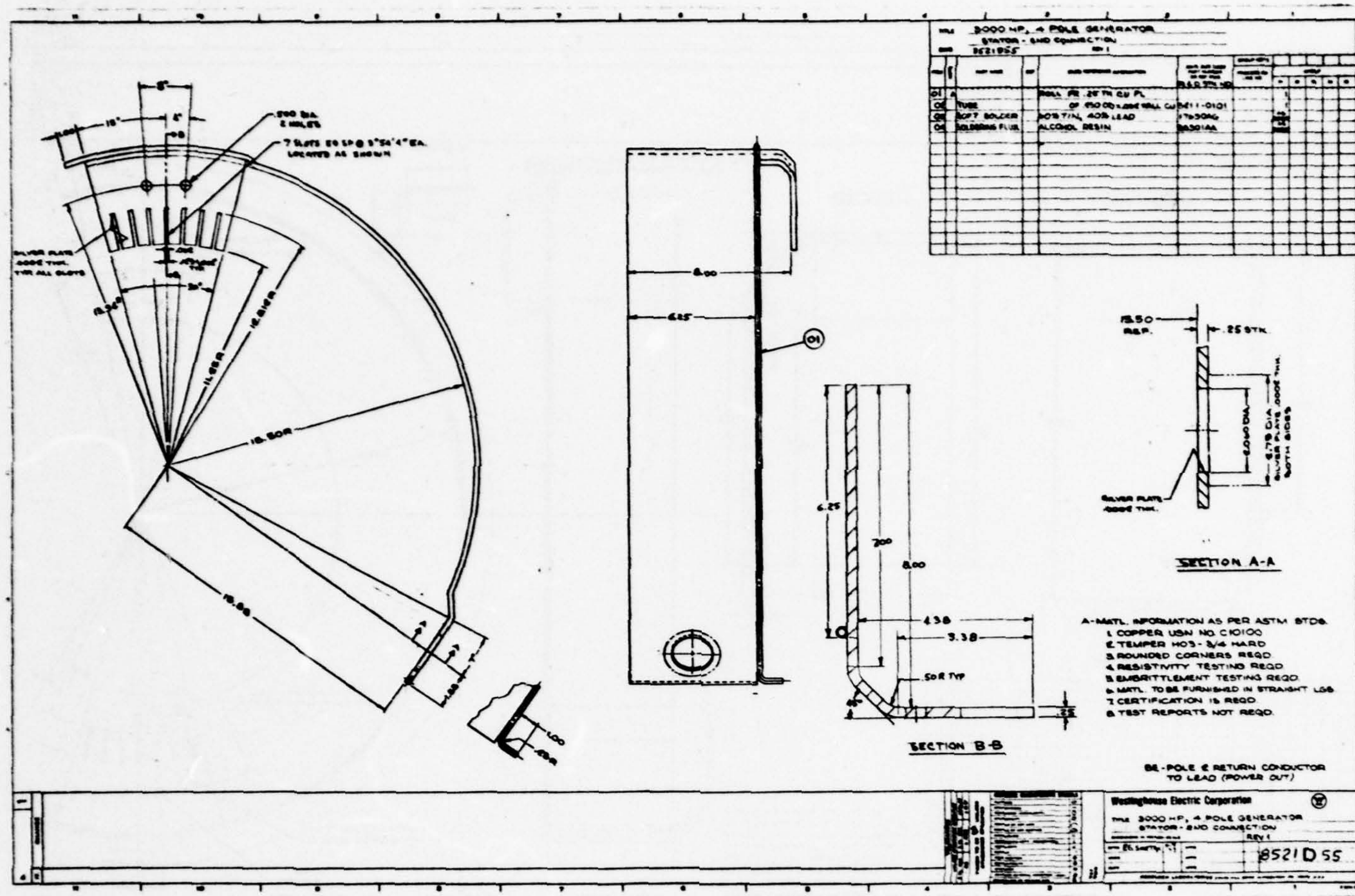


3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
8521D57
01 A RALL FR .25 TH CU PL
02 TUBE .25 OF .5000 × .035 WALL CU 5611-0101
03 SOFT SOLDER 60% TIN, 40% LEAD
04 SOLDERING FLUX ALCOHOL RESIN 8530IAA
02 03 04 AFTER MACHINING, SOLDER IT. 02 TO IT. 01 AS SHOWN
SILVER PLATE .0005 THK.
SILVER PLATE .0005 THK.
11.12 R
14.88 R
66°
28°
11.6
01
6.25
8.50
4.00
.50R
8.50
6.25
.25
SECTION A-A
A - MATL. INFORMATION AS PER ASTM STDS.
1. COPPER UNS NO. C10100
2. TEMPER H03 - 3/4 HARD
3. ROUNDED CORNERS REQD.
4. RESISTIVITY TESTING REQD.
5. EMBRITTLEMENT TESTING REQD.
6. MATL. TO BE FURNISHED IN STRAIGHT LGS.
7. CERTIFICATION IS REQD.
8. TEST REPORTS NOT REQD.
BE - POLE 2 BRUSH HOLDER TO POLE 3 BRUSH HOLDER
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
8521D57

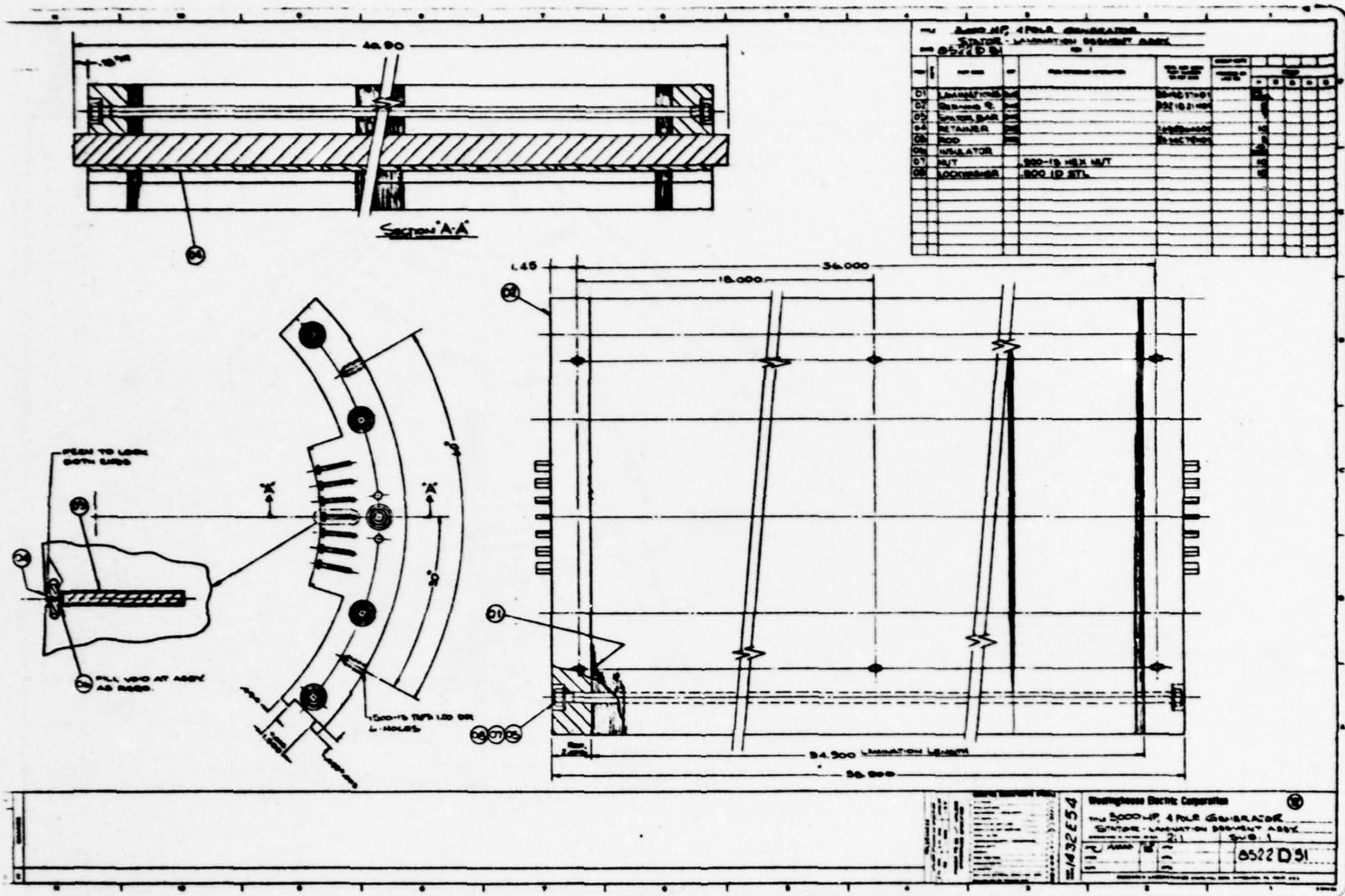

A-MATL. INFORMATION AS PER ASTM STDS
1. COPPER UNS NO. C10100
2. TEMPER H03 - 3/4 HARD
3. ROUNDED CORNERS REQD
4. RESISTIVITY TESTING REQD
5. EMBRITTLEMENT TESTING REQD
6. MATL. TO BE FURNISHED IN STRAIGHT LGS.
7. CERTIFICATION IS REQD.
8. TEST REPORTS NOT REQD.
3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
8521D58
01 A
02 TUBE
03 SOFT SOLDER 60% TIN, 40% LEAD
04 SOLDERING FLUX ALCOHOL RESIN
7 SLOTS EQ SP
LOCATED AS SHOWN
SILVER PLATE .0002 THK. TYP. ALL SLOTS
SILVER PLATE .0002 THK.
AFTER MACHINING, SOLDER CU. TUBE TO 17.01 AS SHOWN.
VIEW C-C
SECTION A-A
SECTION B-B
B-POLE 2, RETURN CONDUCTOR TO POLE 1, BRUSH HOLDER
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
1:2
REV 1
8521D58

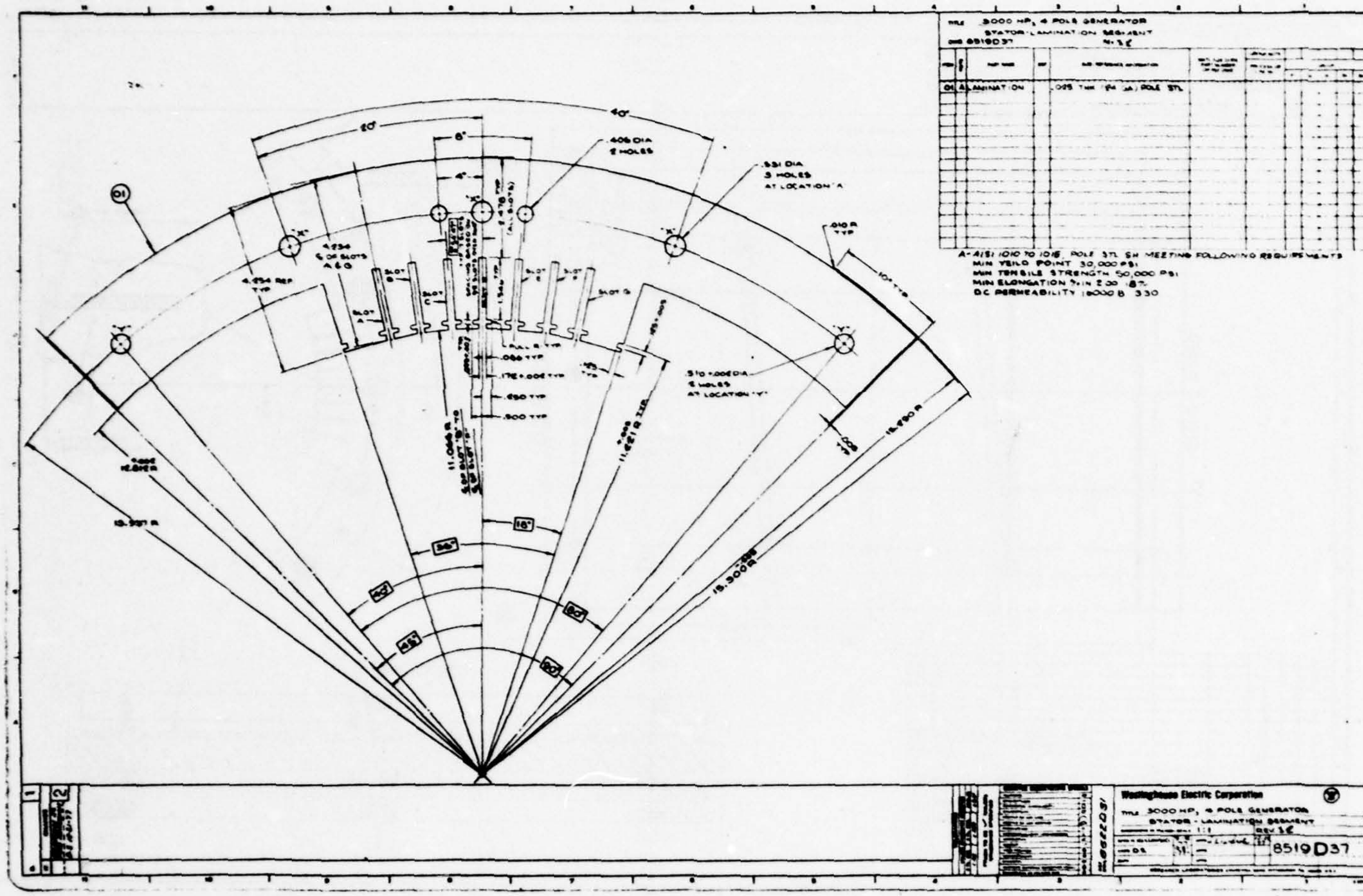

A - MATL. INFORMATION AS PER ASTM STDS.
1. COPPER UNS NO 10100
2. TEMPER HOS - 3/4 HARD
3. ROUNDED CORNERS REQD.
4. RESISTIVITY TESTING REQD
5. EMBRITTLEMENT TESTING REQD
6. MATL TO BE FURNISHED IN STRAIGHT LGS.
7. CERTIFICATION IS REQD.
8. TEST REPORTS NOT REQD.
3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
TUBE
SOFT SOLDER
SOLDERING FLUX
60% TIN, 40% LEAD
ALCOHOL RESIN
1765DA6
B3301AA
7 SLOTS EQ SP
LOCATED AS SHOWN
4 PLACES
SILVER PLATE
TYP ALL SLOTS
.500 DIA
4 HOLES
AFTER MACHINING, SOLDER
14.88R
12.800
11.94R
60°
30°
6.25
8.00
3.88
.38R
SECTION A-A (TYP)
06 - POLE 1 RETURN CONDUCTOR TO
POLE 4 RETURN CONDUCTOR
Westinghouse Electric Corporation
3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
8521D56


A-MATL. INFORMATION AS PER ASTM STDS
1. COPPER UNS NO. C10100
2. TEMPER H03 - 3/4 HARD
3. ROUNDED CORNERS REQD
4. RESISTIVITY TESTING REQD
5. EMBRITTLEMENT TESTING REQD
6. MATL. TO BE FURNISHED IN STRAIGHT LGS
7. CERTIFICATION IS REQD
8. TEST REPORTS NOT REQD
3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
TUBE
SOFT SOLDER
60% TIN, 40% LEAD
SOLDERING FLUX
ALCOHOL RESIN
.500 DIA 2 HOLES
7 SLOTS EQ SP @ 3°54' EA LOCATED AS SHOWN
SILVER PLATE .0002 THK TYP. ALL SLOTS
SILVER PLATE .0002 THK.
VIEW C-C
AFTER MACHINING, SOLDER ALL TUBS. TO IT.01 AS SHOWN.
SECTION A-A
SECTION B-B
BE - POLE 3, RETURN CONDUCTOR TO POLE 1, BRUSH HOLDER
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
1:2
REV 1
8521 D 58

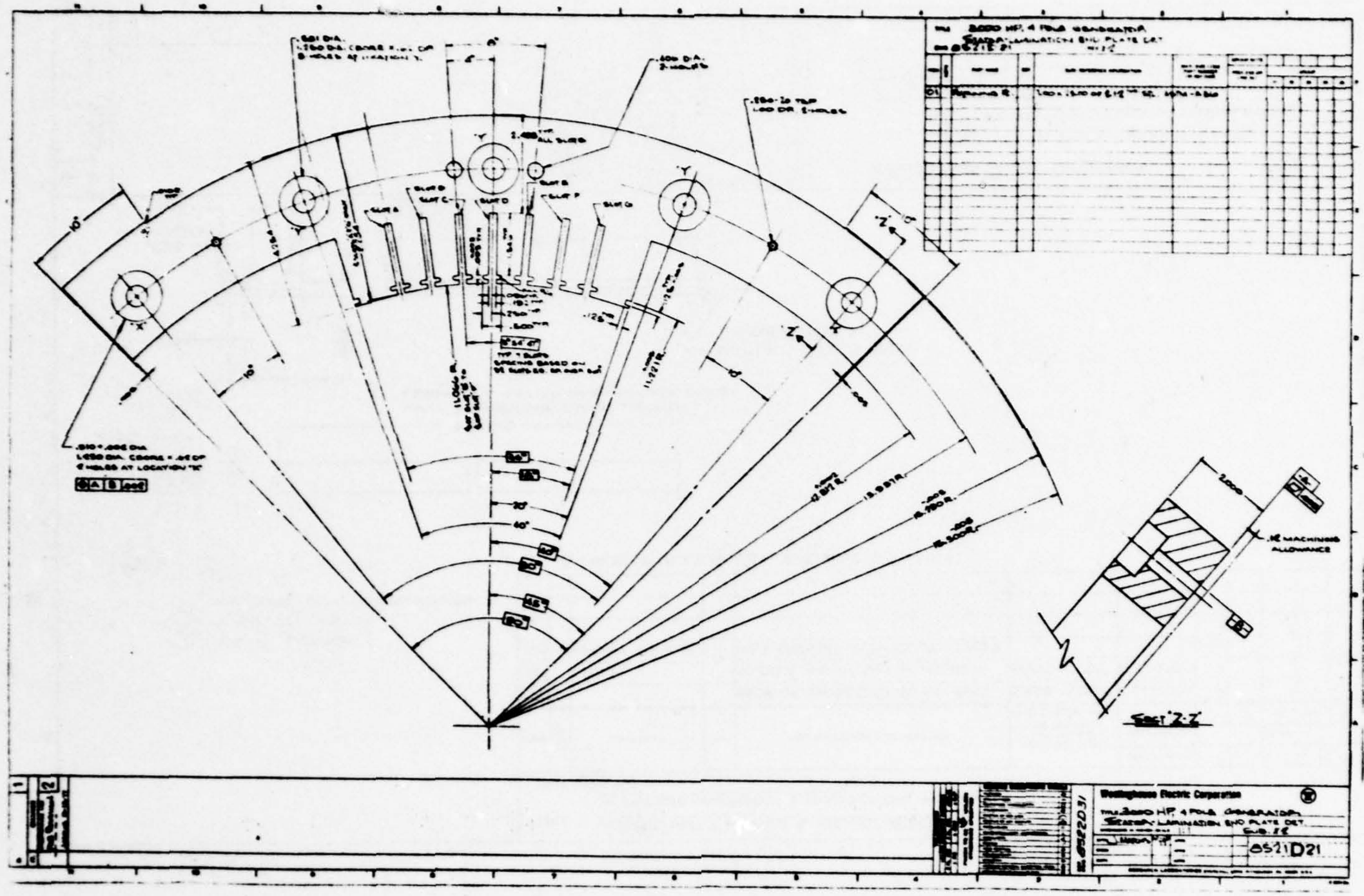


3000 HP, 4 POLE GENERATOR
STATOR - END CONNECTION
8521D55
01 ROLL FR .25 TH CU PL
02 TUBE OF .750 OD x .006 WALL CU
03 SOFT SOLDER 60% TIN, 40% LEAD
04 SOLDERING FLUX ALCOHOL RESIN
.200 DIA. 2 HOLES
7 SLOTS EQ SP @ 3°34'4" EA. LOCATED AS SHOWN
SILVER PLATE .0005 THK. TYP. ALL SLOTS
18.50R
19.88
8.00
6.25
01
7.00
4.38
3.38
.50R TYP
.25
SECTION B-B
15.50 REF.
.25 STK.
2.00 DIA.
2.75 DIA. SILVER PLATE .0005 THK. BOTH SIDES
SILVER PLATE .0005 THK.
SECTION A-A
A-MATL. INFORMATION AS PER ASTM STDS.
1. COPPER USN NO. C10100
2. TEMPER H03 - 3/4 HARD
3. ROUNDED CORNERS REQD
4. RESISTIVITY TESTING REQD
5. EMBRITTLEMENT TESTING REQD
6. MATL. TO BE FURNISHED IN STRAIGHT LGS
7. CERTIFICATION IS REQD
8. TEST REPORTS NOT REQD.
BE-POLE & RETURN CONDUCTOR TO LEAD (POWER OUT)
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR STATOR - END CONNECTION
REV 1
8521D55


Westinghouse Electric Corporation
5000 HP, 4 POLE GENERATOR
STATOR - LAMINATION SEGMENT ASSY
8522D51
1432E54
SECTION 'A-A'
40.90
36.000
18.000
1.45
34.900 LAMINATION LENGTH
36.900
LAMINATION
RETAINER
ROD
INSULATOR
NUT
LOCKWASHER
.500-13 HEX NUT
PEEN TO LOCK BOTH SIDES
FILL VOID AT ASSY AS REQD.
4 HOLES



TITLE 3000 HP, 4 POLE GENERATOR
STATOR LAMINATION SEGMENT
DWG 8519D37
01 A LAMINATION .025 THK (24 GA) POLE STL
A - AISI 1010 TO 1015, POLE STL SH MEETING FOLLOWING REQUIREMENTS
MIN YEILD POINT 30,000 PSI
MIN TENSILE STRENGTH 50,000 PSI
MIN ELONGATION % IN 2.00 18%
DC PERMEABILITY 10000 B 330
.406 DIA
2 HOLES
.531 DIA
3 HOLES
AT LOCATION X
.510 DIA
2 HOLES
AT LOCATION Y
SLOT A
SLOT B
SLOT C
SLOT D
4.734
5 OF SLOTS
A & G
4.734 REF
TYP
.086 TYP
.500 TYP
11.066 R
15.300 R
15.551 R
20°
40°
8°
4°
16°
36°
45°
90°
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
STATOR LAMINATION SEGMENT
8519D37



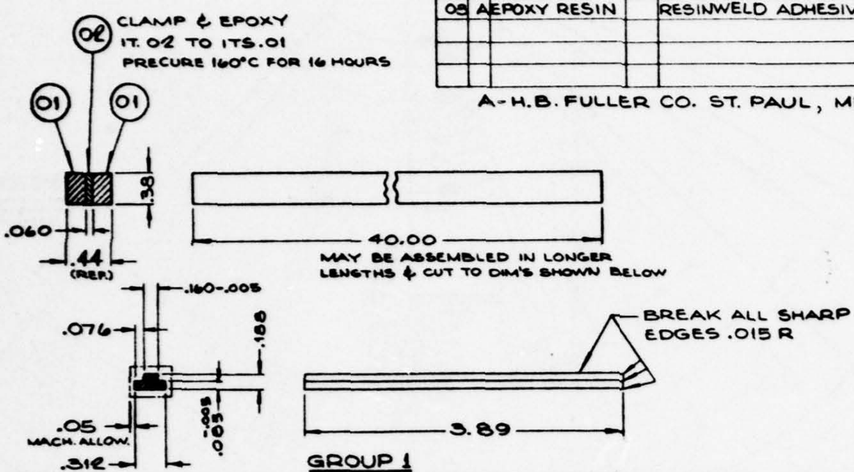
2000 HP, 4 POLE GENERATOR
STATOR LAMINATION END PLATE DET.
SECT "Z-Z"
MACHINING ALLOWANCE
Westinghouse Electric Corporation
8521D21

TITLE 3000 HP, 4 POLE GENERATOR
STATOR - RETURN CONDUCTOR WEDGE

DWG 1692B64 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STK NO	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01				84.00 OF .18X.38 RECT CD STL BAR	5809-0301	AISI C101B	2				
02		INSUL		40.00X.38 OF .06 THK MICARTA	8807-0101	GRADE #221	1				
03	A	EPOXY RESIN		RESINWELD ADHESIVE 7007			AS REQD				

A - H.B. FULLER CO. ST. PAUL, MINN.



TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL. DEC ±.02; 3 PL. DEC ±.005; ANGLES ±0.5°

FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS: FLATNESS; STRAIGHTNESS; ROUNDNESS (CIRCULARITY); CYLINDRICITY; PROFILE OF ANY LINE; PROFILE OF ANY SURFACE; PARALLELISM; PERPENDICULARITY (SQUARENESS); ANGULARITY; RUNOUT; TRUE POSITION; CONCENTRICITY; SYMMETRY; MAXIMUM MATERIAL CONDITION (MMC); REGARDLESS OF FEATURE SIZE

REF DWG

CHANGE | D. | IT. | 1

Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
STATOR - RETURN CONDUCTOR WEDGE

DIMENSIONS IN INCHES - SCALE NTS REV. 1

DFTM H. Koslowski 12-6-77 APPD
CHKD APPD
SUPV APPD

1692B64

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

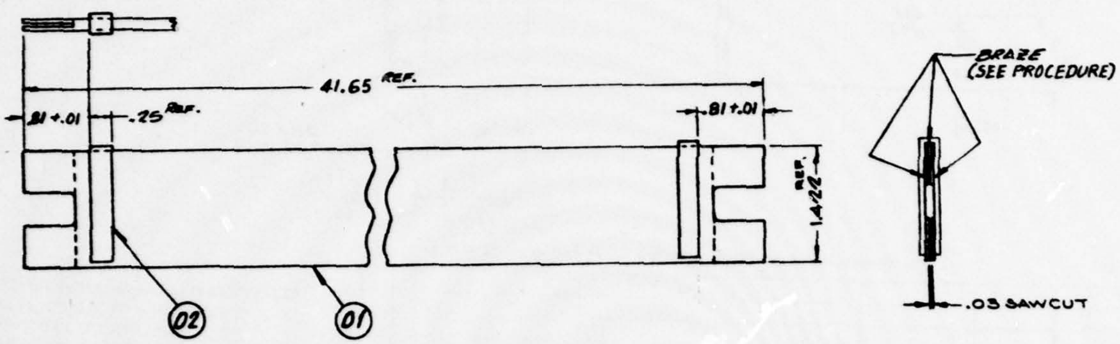
BRAZING PROCEDURE

1. CLEAN THE COPPER AS PER DWG. 6440A40.
2. ASSEMBLE THE PARTS TO BE BRAZED WITH .005 X APPROPRIATE AREA COPPER-SILVER-PHOSPHORUS BRAZING ALLOY (PDS 13402VJ) STRIP BETWEEN THE SURFACES TO BE BRAZED.
3. STACK THE PIECES SO THAT THEIR WEIGHT MAINTAINS PRESSURE ON THE BRAZED JOINT DURING HEATING. YOU MAY HAVE TO SUPPORT THE COPPER BARS AT THEIR CENTERS WITH BLOCKS BETWEEN EACH LAYER TO PREVENT DISTORTION.
4. HEAT IN A FURNACE WITH AN ARGON ATMOSPHERE TO 1340-1370° F AND HOLD LONG ENOUGH TO OBTAIN UNIFORM TEMPERATURE THROUGHOUT.
5. COOL IN ARGON, INSPECT.

TITLE 3000 HP, 4 POLE GENERATOR STATOR RETURN CONDUCTOR

DWG 1696B80 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		CONDUCTOR BAR	DWG		1693B30H01		1				
02		BACKUP COLLAR	DWG		861AC72H05		2				



TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG

CHANGE

...stinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR STATOR RETURN CONDUCTOR

DIMENSIONS IN INCHES—SCALE 1:1

DFTM J. MARKS

CHKD

SUPV

1696 B 80

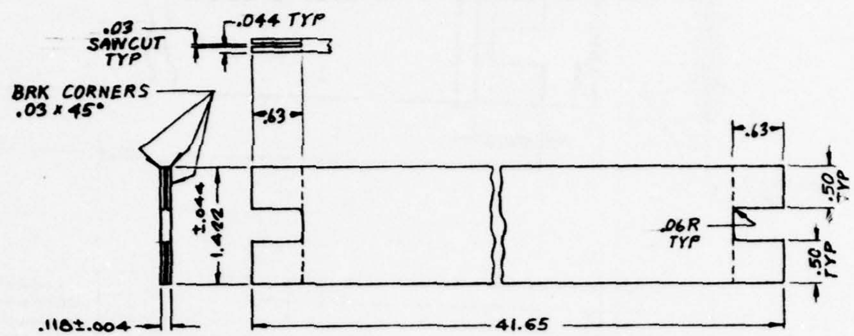
RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA 15235 U.S.A.

TITLE 3000 HP, 4 POLE GENERATOR
STATOR - RETURN CONDUCTOR BARS
DWG 1693B30 REV 1

NOTES:
1. COPPER UNS No. C10100
2. TEMPER H03 - 3/4 HARD
3. ROUNDED EDGES
4. RESISTIVITY TEST REQUIRED
5. EMBRITTLEMENT TEST REQUIRED
6. MATERIAL FURNISHED IN STRAIGHT LENGTHS
7. CERTIFICATION REQUIRED
8. TEST REPORTS NOT REQUIRED

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	CONDUCTOR BAR			ASTM B152-77						

A - PDS 13406CB MAY BE SUPPLIED AS ALTERNATE



TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL DEC ±.02; 3 PL DEC ±.005; ANGLES ±0.5°
FINISH TO BE 63 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS: FLATNESS; STRAIGHTNESS; ROUNDNESS (CIRCULARITY); CYLINDRICITY; PROFILE OF ANY LINE; PROFILE OF ANY SURFACE; PARALLELISM; PERPENDICULARITY (SQUARENESS); ANGULARITY; RUNOUT; TRUE POSITION; CONCENTRICITY; SYMMETRY; MAXIMUM MATERIAL CONDITION (MMC); REGARDLESS OF FEATURE SIZE

REF DWG 1696B80

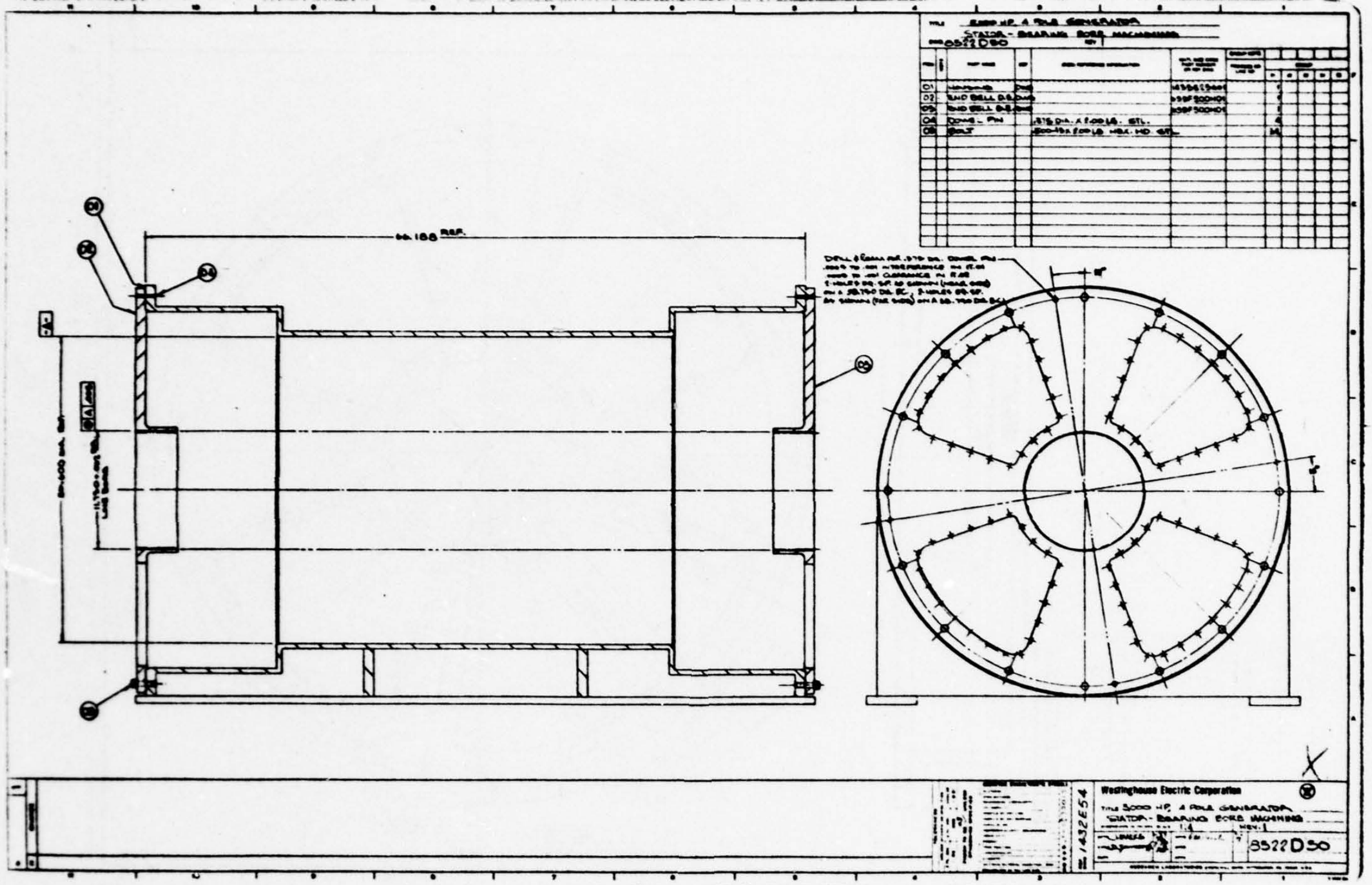
CHANGE 1

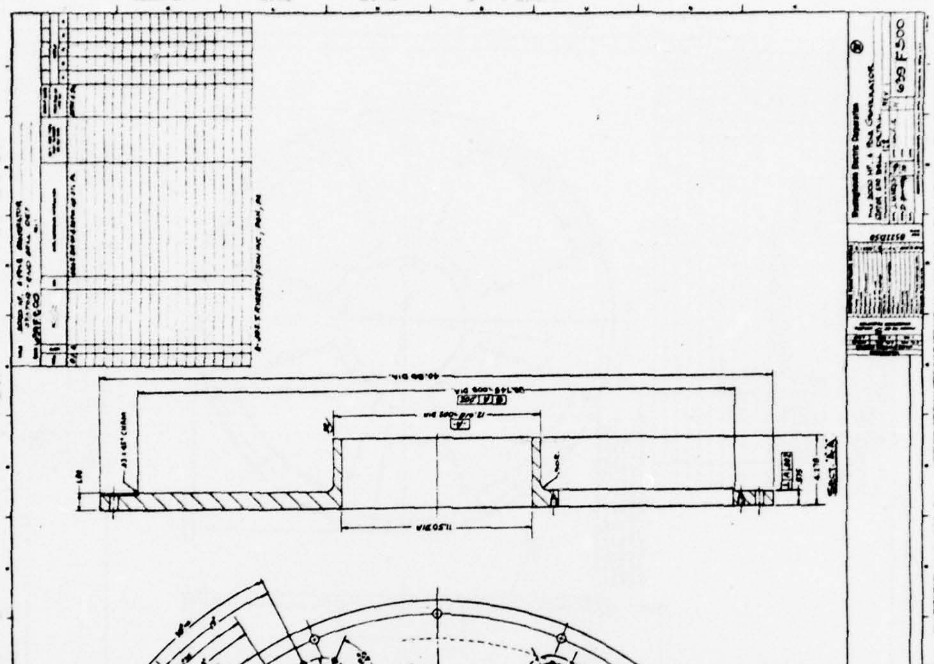
Westinghouse Electric Corporation

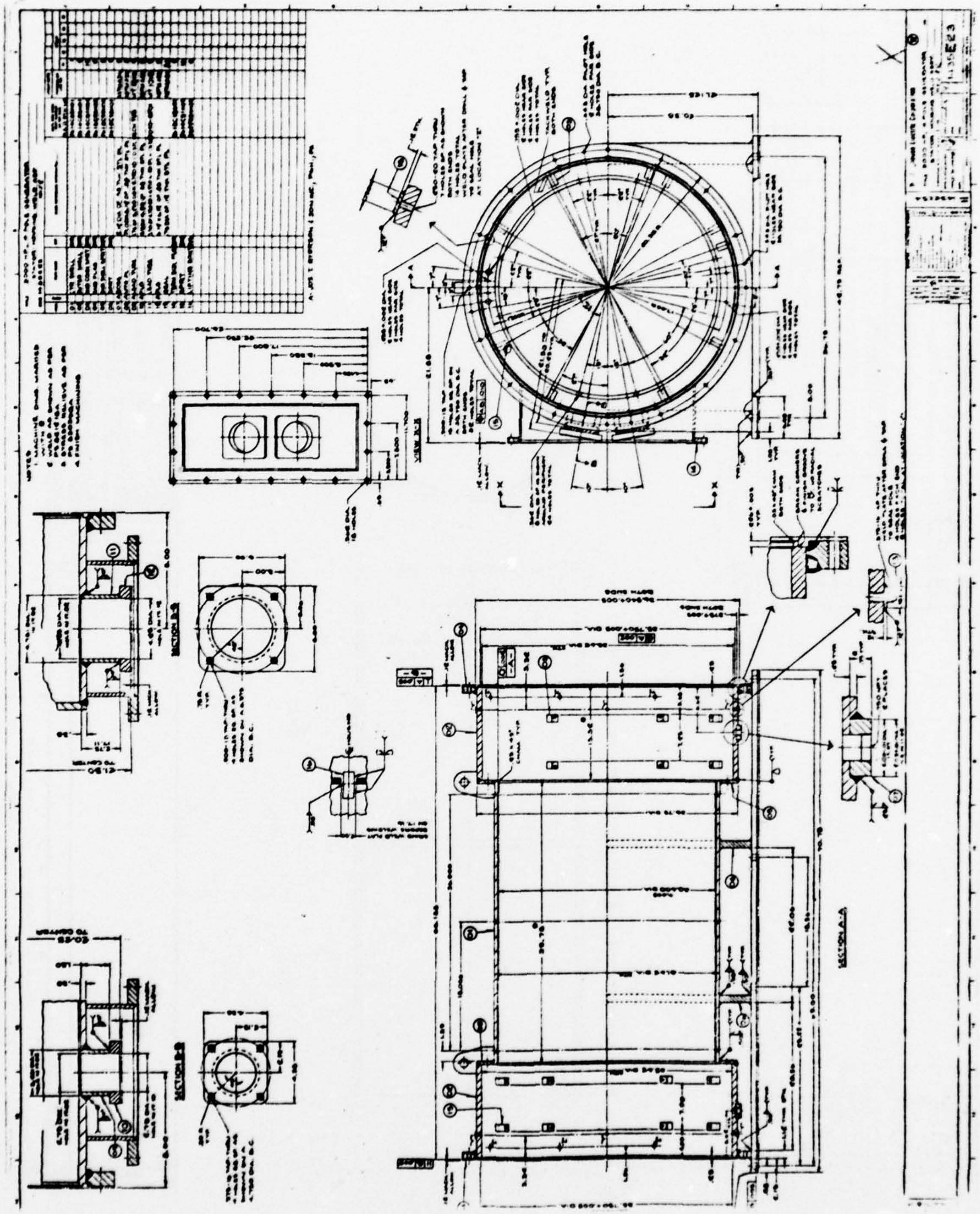
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - RETURN CONDUCTOR BARS
DIMENSIONS IN INCHES—SCALE 1:1 REV 1
DFTM H. Kralowski 1-12-78 APPD
CHKD APPD
SUPV APPD

1693B30

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.


Westinghouse Electric Corporation
TITLE 5000 HP, 4 POLE GENERATOR
STATOR - BEARING BORE MACHINING
1:4
REV. 1
8522D50
1432E54
.375 DIA. X 2.00 LG. STL.
66.188 REF.

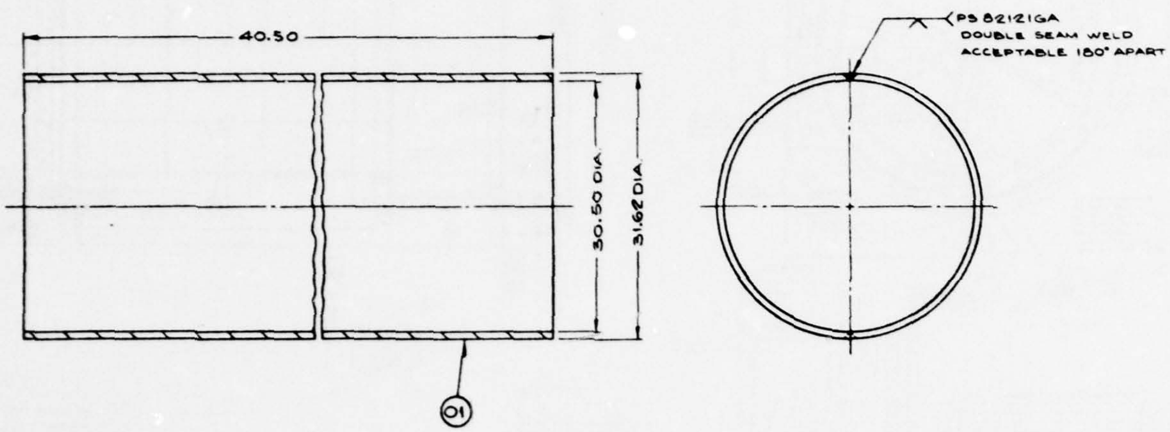

Westinghouse Electric Corporation
639F300
SECT A-A



TITLE 3000 HP, 4 POLE GENERATOR
STATOR - HOUSING SHELL (CENTER)
DWG 2614C85 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01				ROLL FROM STL PL		ASTM A-36					

NOTE:
ROLL, WELD, STRESS RELIEVE AND MACHINE TO DIMENSIONS SHOWN

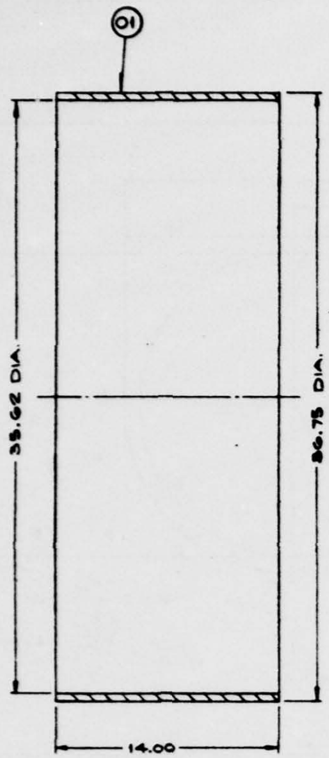


REF DWG 1435E23

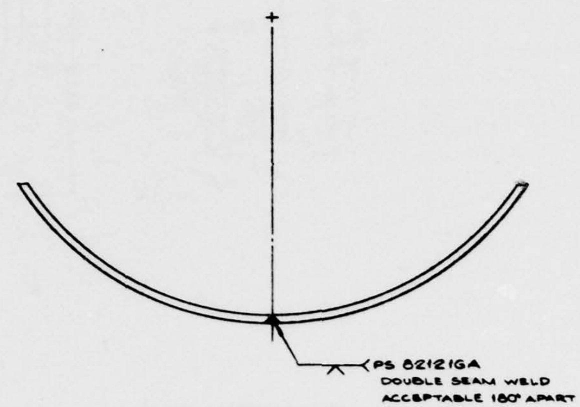
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
STATOR - HOUSING SHELL (CENTER)
REV. 1
DWN R. Kozlowski
2614C85
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

TITLE 3000 HP, 4 POLE GENERATOR
STATOR - HOUSING SHELL (END)
DWG 2614C86 REV 1

ITEM	NOTE	PART NAME	DSP	(SEE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO
01				ROLL FROM STL PL		ASTM A-36



NOTE:
ROLL, WELD, STRESS RELIEVE AND MACHINE TO DIMENSIONS SHOWN



REF DWG 1435E23

Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
STATOR - HOUSING SHELL (END)
NTS REV 1

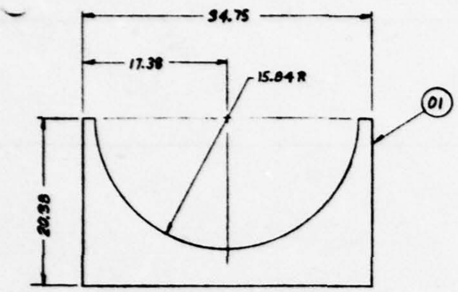
2614C86

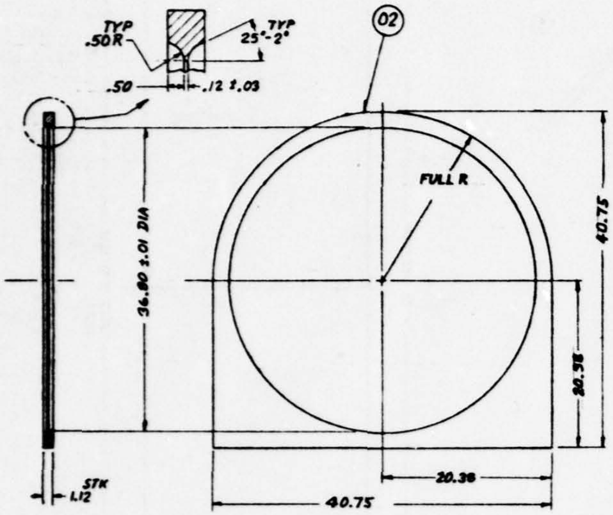
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

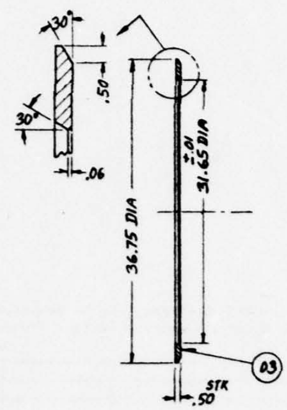
TITLE 3000 HP. 4 POLE GENERATOR
STATOR - SPRT FLG, FACE FLG & RING DETS
DWG 2618C98 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO
01	A	SPRT FLG		MAKE FROM 1.00 THK HR STL PL		ASTM A 36
02	A	FACE FLG		MAKE FROM 1.12 THK HR STL PL		ASTM A 36
03	A	RING		MAKE FROM .50 THK HR STL PL		ASTM A 36

A - JOS. T. RYERSON & SON INC, PGH., PA.







Westinghouse Electric Corporation

TITLE 3000 HP. 4 POLE GENERATOR
STATOR - SPRT FLG, FACE FLG & RING DETS.

DIMENSIONS IN INCHES—SCALE 1:8 REV 1

DFTS C. HOHMAN 6-15

REF DWG 1435E23

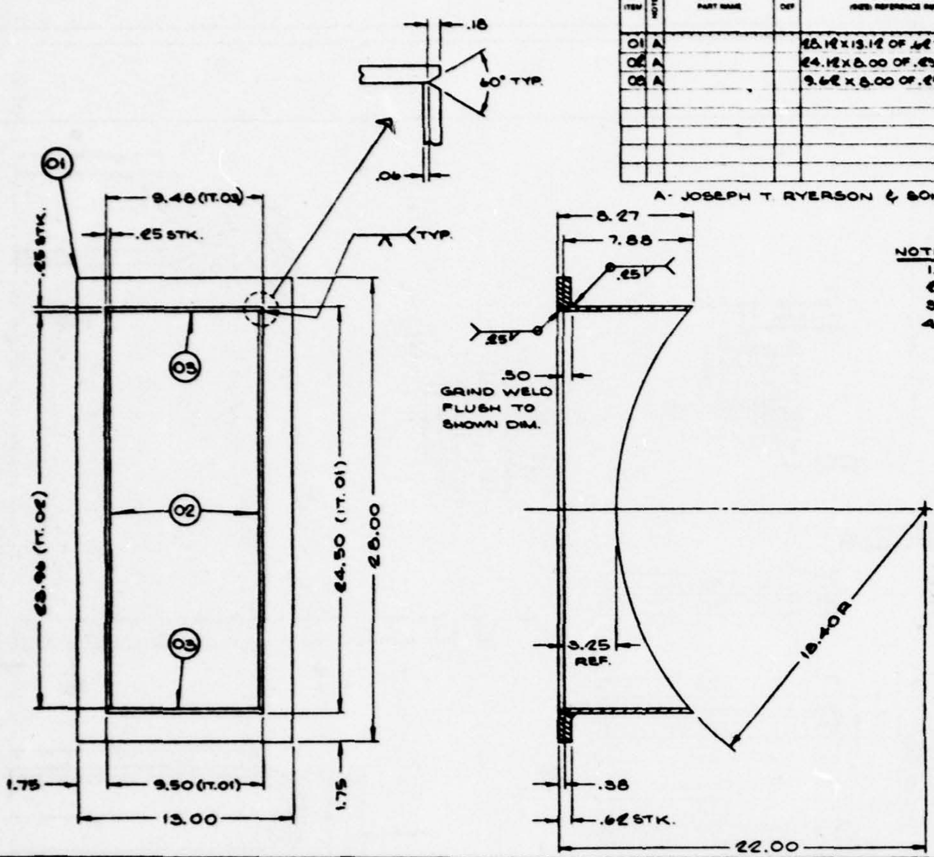
2618C98

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

TITLE 3000 HP, 4 POLE GENERATOR
STATOR - TERMINAL BOX FLANGE
DWG 2618C18 REV 1

ITEM	NOTE	PART NAME	QTY	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP				
01	A			28.12 X 13.12 OF .62 THK STL PL		ASTM A36	1				
02	A			24.12 X 8.00 OF .25 THK STL PL		ASTM A36	2				
03	A			9.62 X 8.00 OF .25 THK STL PL		ASTM A36	2				

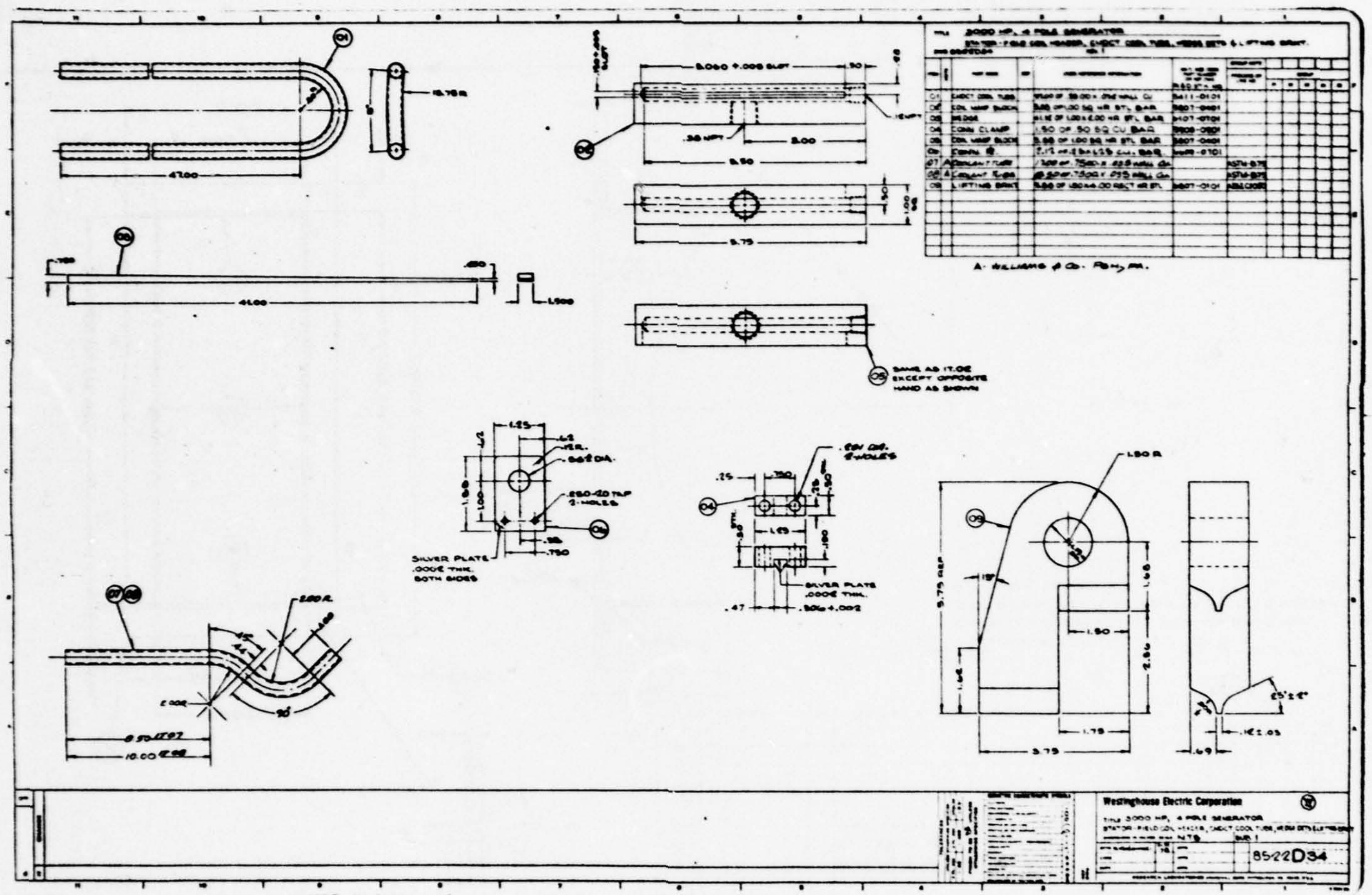
A - JOSEPH T. RYERSON & SON, INC., PGH., PA.



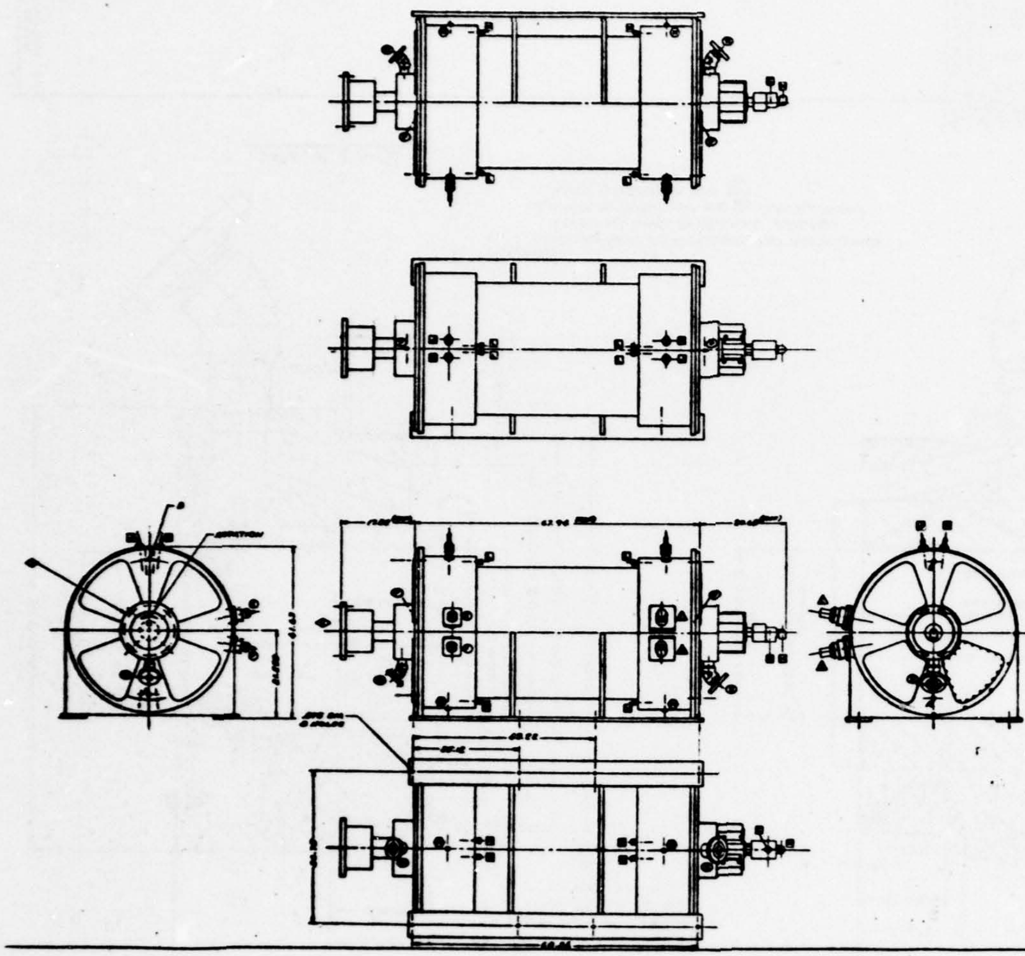
NOTES:
1. MACHINE CUTOUT IN IT. 01
2. WELD AS SHOWN AS PER PS 82121GA
3. STRESS RELIEVE AS PER PS 83030QA
4. FINISH MACHINE

Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
STATOR - TERMINAL BOX FLANGE
1:4 REV. 1
REF DWG 1435E23
2618C18



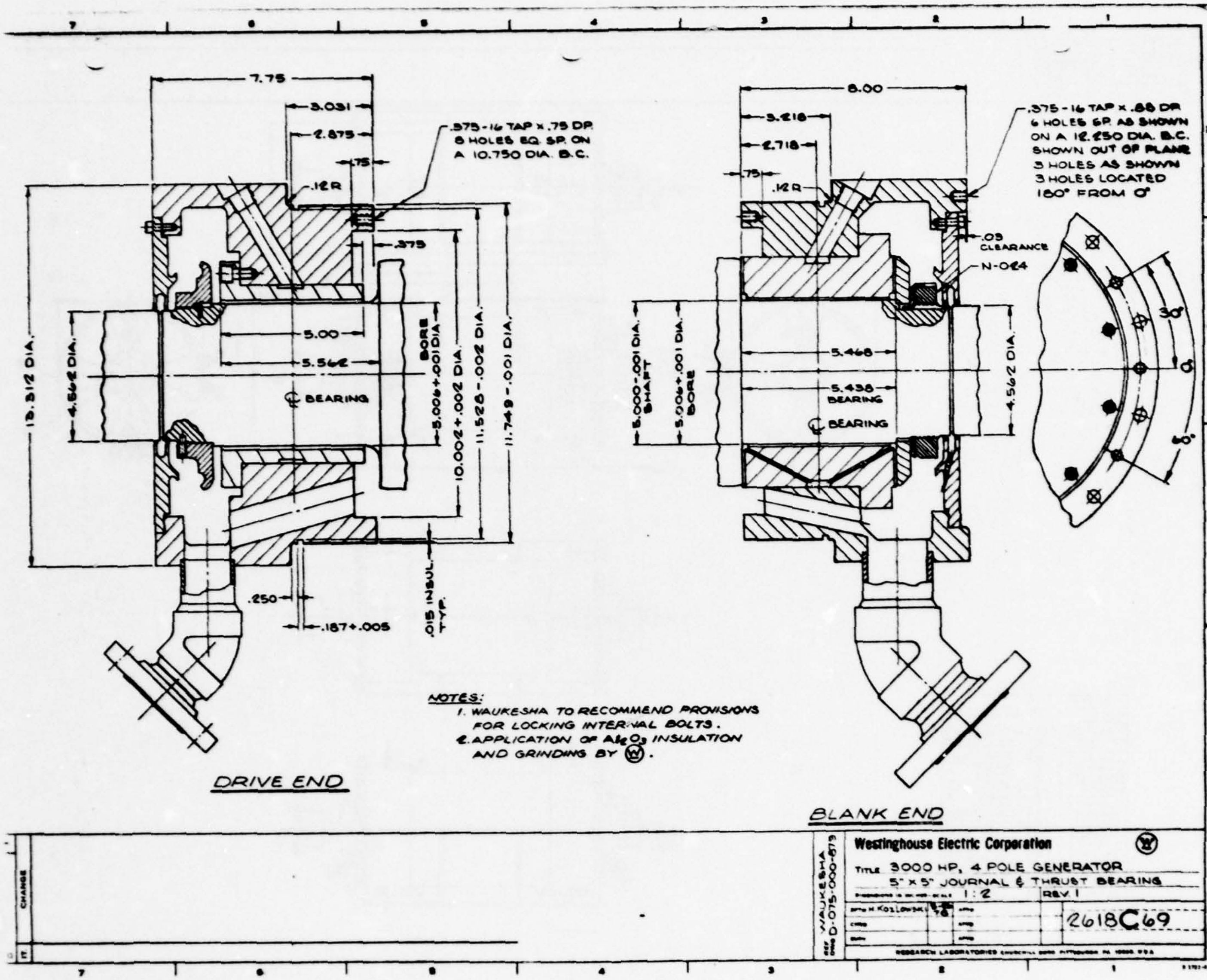
3000 HP, 4 POLE GENERATOR
A. WILLIAMS & CO. PGH, PA.
SAME AS 17.05 EXCEPT OPPOSITE HAND AS SHOWN
SILVER PLATE .0002 THK. BOTH SIDES
SILVER PLATE .0002 THK.
Westinghouse Electric Corporation
NTS
8522D34



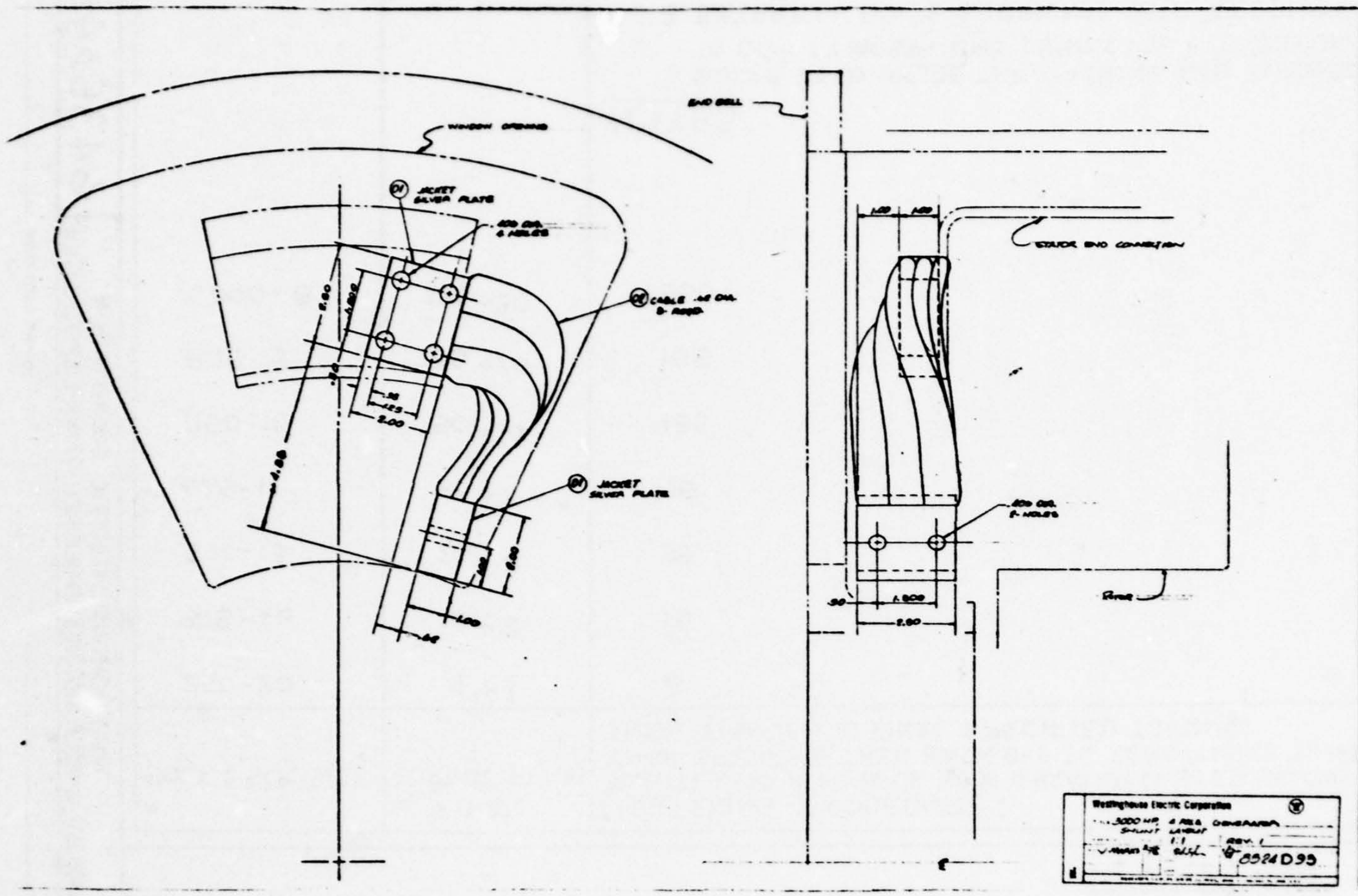
INTERFACE FUNCTION		CODE SYM	QTY	INTERFACE TYPE
COVER GAS INLET		A	2	.38 NPT
COVER GAS OUTLET		B	2	.38 NPT
END CONNECTION POWER IN		△	1	2.00-12 THD
END CONNECTION POWER OUT		△	1	2.00-12 THD
FIELD COIL POWER IN			1	.50-13 THD
FIELD COIL POWER OUT			1	.50-13 THD
COOLANT LINES	ROTOR IN		1	1.00 NPT
	ROTOR OUT		1	.75 NPT
	STATOR IN		2	.75 OD TUBE
	STATOR OUT		2	.75 OD TUBE
	VENTS		4	.25 TUBE FTG
	DRAINS		4	.25 TUBE FTG
SHELL DRAIN			2	.75 NPT
BEARING OIL IN			2	.50 NPT
BEARING OIL OUT			1	1.50 FLG [illegible]
THRUST BRG OIL OUT			1	2.00 FLG [illegible]
FAST'S COUPLING KOPPERS CO., INC.			1	SIZE 4, [illegible]

MISC
X

Westinghouse Electric Corporation
3000 HP, 4 POLE GENERATOR
OUTLINE INTERFACE DWG
1/8 REV 1
1435E29



7.75
3.031
2.875
.75
.12R
.375-16 TAP x .75 DP.
8 HOLES EQ. SP. ON
A 10.750 DIA. B.C.
.375
5.00
5.562
℄ BEARING
BORE
5.006+.001 DIA.
10.002+.002 DIA.
11.528-.002 DIA.
11.749-.001 DIA.
13.312 DIA.
4.562 DIA.
.250
.187+.005
.015 INSUL. TYP.
DRIVE END
8.00
3.218
2.718
.75
.12R
.375-16 TAP x .88 DP.
6 HOLES SP. AS SHOWN
ON A 12.250 DIA. B.C.
SHOWN OUT OF PLANE
3 HOLES AS SHOWN
3 HOLES LOCATED
180° FROM 0°
.03 CLEARANCE
N-024
5.000-.001 DIA. SHAFT
5.006+.001 DIA. BORE
5.468
5.438 BEARING
℄ BEARING
4.562 DIA.
30°
0°
60°
BLANK END
NOTES:
1. WAUKESHA TO RECOMMEND PROVISIONS FOR LOCKING INTERNAL BOLTS.
2. APPLICATION OF Al_2O_3 INSULATION AND GRINDING BY Ⓦ.
Westinghouse Electric Corporation
TITLE 3000 HP, 4 POLE GENERATOR
5" x 5" JOURNAL & THRUST BEARING
1:2
REV. 1
2618C69
WAUKESHA D-075-000-873
CHANGE


WINDOW OPENING
JACKET SILVER PLATE
.500 DIA. 4 HOLES
CABLE .46 DIA. 8- REQD.
JACKET SILVER PLATE
END BELL
STATOR END CONNECTION
.500 DIA. 2- HOLES
Westinghouse Electric Corporation
3000 HP, 4 POLE GENERATOR
SHUNT LAYOUT
1:1
REV. 1
8524D95

S.O.	SUB.
D.	1
TP 4-20-78	

BOLT & SCR. SIZE	FINAL TORQUE FT./LBS.	TIGHTENING PROCEDURE: TIGHTEN TO A TORQUE 50% GREATER (LISTED BELOW) THAN SPECIFIED. THEN BACK OFF TO ZERO (THREE TIMES) THEN TIGHTEN TO FINAL SPECIFIED TORQUE.
.250-20	4 +1	6
.375-16	10 +2	15
.500-13	26 +4	39
.625-11	50 +5	75
.750-10	90 +10	135
.875-9	130 +20	195
1.000-8	220 +30	330

NOTES:

1. BOLTS USED INSIDE THE MACHINE AND EXPOSED TO CO^2 ATMOSPHERE LUBRICATE WITH "NEOLUBE"
2. EXTERNAL BOLTS LUBRICATE WITH "LEDPLATE"

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.-TORQUE SPECIFICATIONS

6435A48

DIVISION ______ PLANT LOCATION ______

Cleaning Procedure

Cleaning shall consist of three steps:

A. Cleaning with acetone or alcohol followed by
B. Flushing with demineralized water, then
C. Drying

A. Depending on size, shape, accessability, and state of completion, parts may be cleaned by any or all of the following methods:

1. Wiping with lint free cloths saturated with acetone or alcohol
2. Total immersion in acetone or alcohol provided such immersion will not damage any of the component materials - such as insulation
3. Flushing, pumping, or circulating acetone or alcohol through inaccessable crevices, drilled holes and through pipes and tubes

B. Following cleaning, with acetone or alcohol, parts must be cleaned again with demineralized water by any or all of the following methods:

1. Wiping with saturated or moistened lint free cloths
2. Immersion
3. Flushing, pumping, or circulating

C. Following the demineralized water bath, parts may be dried by any of the following methods

1. Wiping with dry lint free cloths
2. Forced air drying
3. Vacuum drying
4. Heating or baking at 150°F
5. Dry nitrogen surging

Note:

When cleaning, hydrostatic and helium leak testing are required by the detail drawing, hydrostatic testing can be performed in conjunction with step B, and helium leak testing may be performed after step C

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR & 4 POLE GEN.

CLEANING PROCEDURE

REV 1

1697B64

S.O.	SUB.
D.	1

MATERIAL CLEANING PROCEDURES FOR BRAZING

Copper & Brass

1. Degrease by solvent wiping with clean cloth or vapor degreasing.
2. Brighten the copper surface by mechanical abrasion with steel wool, Scotchbrite or filing or by bright dipping in a solution containing (by volume) 55% sulfuric acid, 15% nitric acid, 0.5% hydrochloric acid, and balance water. A 10-20 second dip in the acid is sufficient followed by a water rinse, dry.
3. Wipe surfaces to be brazed with a clean cloth dampened with acetone or alcohol, immediately prior to assembly for brazing.

Stainless Steel

1. Degrease by solvent wiping with a clean cloth or by vapor degreasing. All machining cutting fluid and other oil or grease residues must be removed.
2. Immerse in a 15% by volume solution of sulfuric acid in water at about 160°F for approximately 30 minutes.
3. Water rinse
4. Immerse in 10% nitric acid, 0.5% hycrofluoric acid by volume, balance water, at 120°F for approximately 5 minutes
5. Water rinse, allow to dry.

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3000 HP, 4 POLE GENERATOR

6440A40

DIVISION

PLANT LOCATION

DIELECTRIC TESTS FOR SEGMAG ROTOR BARS

The following series of dielectric tests is intended to qualify the rotor bars of the 3000 hp SEGMAG motor and generators. Consultation on appropriate tests to perform was obtained from Dr. T. W. Dakin and Dr. A. I. Bennett of the Electrical Performance of Insulating Materials Department. In addition the relevant Military Specification, MIL-G-18473A (SHIPS), was checked to determine required tests.

The testing will be done at three stages of manufacture. The isolated bars will be tested following the completion of rotor bar fabrication (test A). The rotor and commutator bar assembly will be connected after completion of soldering together the circuit (test B). Finally, the complete rotor winding will be tested after assembly of the rotor (test C). The details of these three tests follows.

TEST A

First, several (2 or 3 each for motor and generator) bars will be tested to destruction to determine the average breakdown strength of the insulation. Sixty cycle, ac voltage will be used. The RMS value of the average breakdown voltage will be designated V_{BD}. This is expected to be in the range 10-15 kV.

The second part of this test will be to test the remainder of the bars at an RMS voltage V_A and that $V_{BD} > V_A > 2000$ volts. This should be chosen to be considerably below breakdown, in order not to inadvertently damage any of the bars, but still well above the final test voltage, 2000 volts. A probable value for V_A will be 5000 volts. Any bar in which the insulation breaks down at this level will, of course, be rejected.

As an additional check, the corona onset voltage will be recorded for each bar during this test. An average value of this corona onset voltage will be determined, and any bar deviating significantly from this average corona onset voltage ($\pm$ 30% ?) will be regarded with suspicion, pending further examination.

The method of carrying out this test will be to place aluminum bars on the top and bottom of the rotor bars, terminating .75 inch from the ends of the insulated section. The voltage will then be applied between these aluminum bars and the rotor bar copper. The test will be done by Dr. Bennett.

TEST B

A second ac voltage, V_B, will be chosen such that $V_A > V_B > 2000$ volts. A probable value of V_B is 3500 volts. This will be applied between the commutator bar and the rotor iron (ground). Any evidence of incipient breakdown during this test will be cause for rejection of the rotor and commutator bar assembly.

TEST C

This is the test required by MIL Spec. MIL-G-18473A. A 60 cycle RMS voltage of 2000 volts will be applied between the rotor winding and the rotor iron (ground). This test will follow the satisfactory completion of the insulation resistance measurement. All motor bars will be shorted together for this test. Test duration will be sixty seconds.

Westinghouse Electric Corporation

3000 HP, 4 Pole Gen & 6 Pole Motor
Rotor-Dielectric Test for Conductor Bars

Rev 1

1698B66

9

APPENDIX NO. 9

3000 HORSEPOWER, 6 POLE MOTOR DRAWINGS

	REV
6425A42G02 - Rotor ~ Rotating Union	1
6427A71 - Rotor Conductor	1
6433A16 - Insulated Soc. Cyl. Hd. Cap Scr.	1
6435A48 - Torque Specifications	1
6439A64 - Brazing Spec. - Cross Connectors	1
6439A65 - Brazing Spec. - End Connectors	1
6439A66 - Brazing Spec. - Manifolds	1
6439A67 - Brazing Spec. - Riser	1
6439A99 - Brazing Spec. - Stator Tube Fitting	1
1692B10 - Commutator Bar	1
1692B11 - End Cap ~ Rotor Cooling Water End	1
1692B12 - Baffle Tube ~ Rotor Cooling ~ Roll, Weld, Mach.	1
1692B17 - Shell ~ Stator Hsg., Center ~ Roll, Weld, Mach.	1
1692B22 - Shell ~ Stator Hsg., End Roll, Weld, Mach.	1
1692B46 - Wedge ~ Return Conductor - Lamination	1
1692B69 - Cooling H_2O Block ~ End Connectors ~ Stator	1
1693B52 - Material Ordering Information	1
1696B82 - Shunt Mtg. & Support Block Details	1
1696B84 - Tubing Details	1
1697B05 - Material Ordering Information	1
1697B51 - Stuffing Tube Mtg. Plate Gasket - Term. Box	1
1697B64 - Cleaning Procedure	1
1698B20 - Terminal Lug	1
1698B23 - "O" Ring Detail	1
1698B66 - Dielectric Test for Conductor Bars	1

		REV
2614C74	- Cover ~ Rotor Conductor Cooling Tubes	1
2614C76	- Flange ~ Stator Hsg. ~ Center	2
2614C88	- Flange ~ Stator Hsg. ~ Ends	3
2614C89	- Flange ~ Stator Hsg. ~ Ends	3
2615C07	- End Connector ~ Stator Return Connectors	1
2615C08	- End Connector ~ Return Conductors to Brushes	1
2615C10	- Return Conductor ~ Stator	1
2615C16	- Thrust Collar ~ Rotor Bearing	1
2615C19	- Flux Shield Segments ~ Field Coil ~ Stator	1
2615C20	- Support - Field Coil	1
2615C22	- Insulation Ring ~ Rotor Riser to Finger Plate	1
2615C24	- Cross Connector ~ Stator Return Conductor	1
2615C27	- Connector - End Connector to Brush Shunt	1
2615C32	- Gasket ~ Terminal Box	1
2615C36	- Cross Connector ~ Stator Return Connector	1
2615C75	- 75 - Rotor Stacking Procedure	1
2615C82	- Brush Access Cover Gasket	1
2616C61	- H04 - Rotor Fixture	1
2616C62	- Shunt Detail ~ Brush Holder	1
2616C70	- Riser - Rotor	1
2616C71	- Conductor Detail - Rotor	1
2616C74	- Conductor Bar Manufacturing Procedure	1
2618C13	- Shunt Detail ~ Terminal Box	2
2618C28	- Wiring Procedure ~ Field Coils	1
2618C29	- Stator Assembly Procedure	1
2618C44	- Support - End Connector	1
2618C72	- Stuffing Tube Mtg. Plates ~ Term. Box	1
2618C76	- Term. Box Cover & Gasket Details	1
2618C77	- Term. Box Cover & Gasket Details	1
2619C01	- Hub Driver Modification - Rotor	1

		REV
8521D12	- Field Coil	5
8521D27	- Punching ~ Stator	5
8521D28	- Punching ~ Rotor	6
8521D29	- Finger Plate, Key, Punching Det. Ring, Conductor Key - Rotor	1
8521D30	- Forging - Rotor Shaft	3
8521D31	- Support Ring ~ Commutator Bar ~ Rotor	1
8521D32	- Support Ring ~ Conductor Cooling Tubes ~ Rotor	1
8521D43	- Preliminary Balance & Punching Ass'y ~ Rotor	1
8521D64	- Welded Base ~ Term. Box Mtg.	2
8521D84	- Details - Stator	1
8521D85	- Brush Access Cover Detail	1
8522D05	- Flux Shield Weldment	1
8522D16	- Cross Connector ~ Stator Return Conductor	1
8522D25	- Cross Connector ~ Stator Return Conductor	1
8522D30	- Cross Connector ~ Stator Return Conductor	1
8522D39	- Manifold Detail	1
8522D40	- Manifold Detail	1
8522D47	- Manifold Detail	1
8522D48	- Manifold Detail	1
8522D51	- Manifold Block ~ Field Coil ~ Stator	1
8522D81	- Coolant Guide Details - Rotor	1
8522D83	- Details - Rotor	1
8522D84	- Rotor Sub-Assembly	1
8522D89	- Riser Assembly	1
8525D27	- 6" × 6" Journal Brg. W/Thrust & 6" × 6" Journal Brg. Assemblies	1
8525D30	- Terminal Box	1
8525D31	- Terminal Box	1
8525D62	- Details - Terminal Box	

		REV
639F485	- Finger Plate - Stator	1
639F486	- Rotor Forging Machining	1
639F487	- Rotor Forging Machining	1
639F488	- Coolant Guide Assembly - Rotor	1
639F489	- End Hsg. Weldment - Stator	2
639F490	- Center Hsg. Weldment - Stator	2
639F492	- End Hsg. Weldment - Stator	2
639F493	- Stator Punching Segments - Ass'y.	1
639F495	- End Connectors - Stator	1
639F496	- End Connectors - Stator	1
639F497	- End Connectors - Stator	1
639F503	- Outline Drawing	3
1435E21	- Welding ~ Rotor Forgings	1
1435E22	- Rotor Ass'y. & Final Mach.	1
1435E24	- Stator Hsg. Ass'y. & Brg. Boring	2
1289J20	- Layout (Conceptual)	1
1289J32	- Terminal Box Layout	1
1289J54	- Stator Ass'y.	1
1289J56	- General Ass'y.	1

Westinghouse Electric Corporation R&D CENTER. 1310 BEULAH RD., PITTSBURGH, PA. 15235 USA

TITLE 3000 HP, 4 POLE GENERATOR & 6 POLE MOTOR

ROTOR - ROTATING UNION

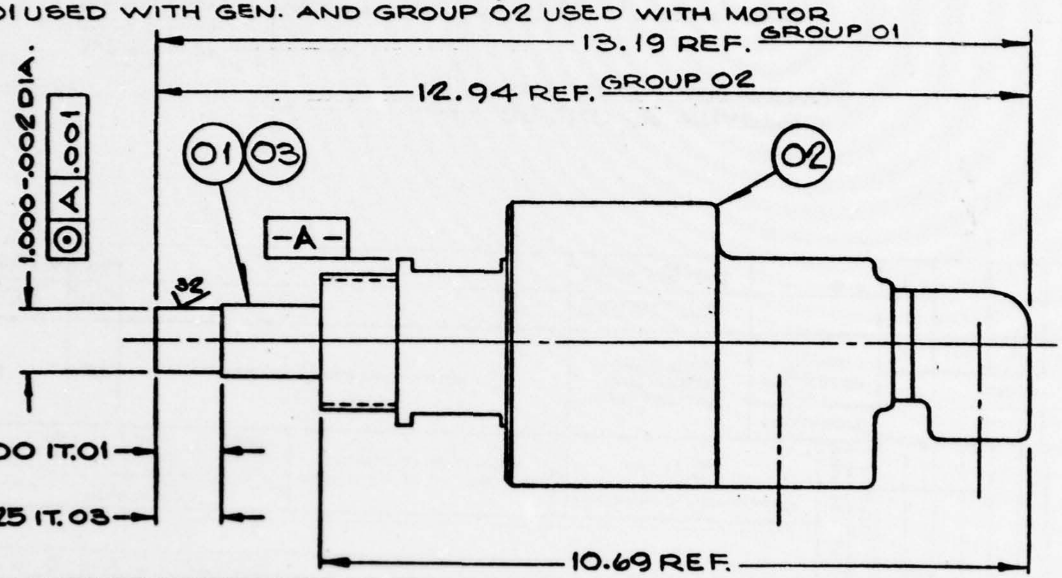
DFTM H.K. 1-11-78 | APPD | SUB. 1

REF DWG	TOLERANCES UNLESS OTHERWISE SPECIFIED			FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED	DIMENSIONS IN INCHES—SCALE
	2 PL. DEC.	3 PL. DEC.	ANGLES		
	±.02	±.005	±0.5°		1:2

TEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01		SYPHON PIPE	DWG		8521D22H03		1				
02	A	ROTATING UNION	BOS	MODEL #555 SST ROTOR #455-8			1	1			
03		SYPHON PIPE	DWG		8521D29H05			1			

A-DEUBLIN COMPANY, NORTHBROOK, ILLINOIS

JOTE: GROUP 01 USED WITH GEN. AND GROUP 02 USED WITH MOTOR



6425A42

/estinghouse Electric Corporation RESEARCH LABORATORIES CHURCHILL BORO, PITTSBURGH, PA 15235, U S A

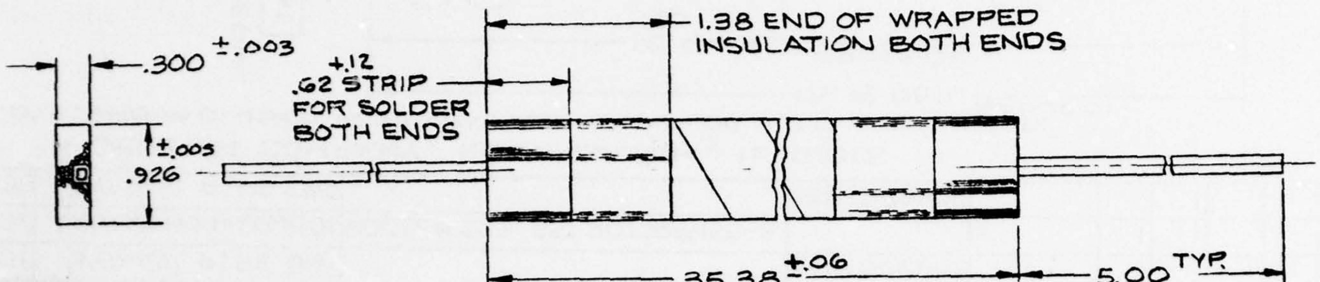
TITLE 3,000 H.P. 6-POLE MOTOR

ROTOR - CONDUCTOR

REF DWG 2616C71

TOLERANCES UNLESS OTHERWISE SPECIFIED			FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED	DIMENSIONS IN INCHES—SCALE	SUB.	DFTM. J.W.S. 2/17/78
2 PL. DEC.	3 PL. DEC.	ANGLES		N.T.S.	1	APPD
±.02	±.005	±0.5°				

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01		CONDUCTOR	DWG		2616C74		1				
02		CLEANING PROCEDURE	DWG		1697B64		REF				



NOTES:

1- CLEAN INSIDE OF TUBING PER DRAWING 1697B64 & TEST AS FOLLOWS:
  (a) HYDROSTATIC TEST AT 100 P.S.I. FOR 30 MINUTES.
  (b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
  (c) HELIUM LEAK TEST PER ASTM E-499 METHOD "A" AT 10 P.S.I.G.
  MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD $1 \times 10^{-6} \frac{CM^3}{S}$

2- DIELECTRIC TESTING WILL BE DONE PER DRAWING 1698B66 BY WESTINGHOUSE.

6427A71

Vestinghouse Electric Corporation RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA 15235 U.S.A.

TITLE 3,000 H.P., 6-POLE MOTOR

INSULATED SOC. CYL. HD. CAP SCR - ROTOR

DFTM. J.W.S. 3/30/78 | SUB. 1 | APPD

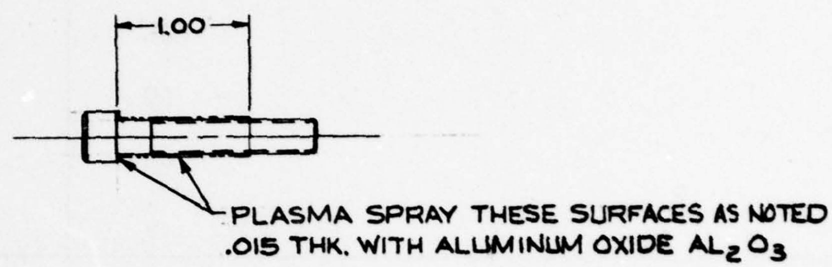
REF DWG 1435E22

TOLERANCES UNLESS OTHERWISE SPECIFIED		
2 PL. DEC.	3 PL. DEC.	ANGLES
±.02	±.005	±0.5°

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

DIMENSIONS IN INCHES—SCALE FULL

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01		CAP SCREW		.250-20 x 1.50 LG. STL.		ASTM-A193-B7	1				



6433A16

S.O.	SUB.
D.	1
T.P.G. 4-20-78	

BOLT & SCR. SIZE	FINAL TORQUE FT./LBS.	TIGHTENING PROCEDURE: TIGHTEN TO A TORQUE 50% GREATER (LISTED BELOW) THAN SPECIFIED. THEN BACK OFF TO ZERO (THREE TIMES) THEN TIGHTEN TO FINAL SPECIFIED TORQUE.
.250-20	4 +1	6
.375-16	10 +2	15
.500-13	26 +4	39
.625-11	50 +5	75
.750-10	90 +10	135
.875-9	130 +20	195
1.000-8	220 +30	330

NOTES:

1. BOLTS USED INSIDE THE MACHINE AND EXPOSED TO CO^2 ATMOSPHERE LUBRICATE WITH "NEOLUBE"
2. EXTERNAL BOLTS LUBRICATE WITH "LEDPLATE"

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.-TORQUE SPECIFICATIONS

6435A48

DIVISION

PLANT LOCATION

S.O.	SUB.
D.	1
R. 6-5-78	

Brazing Specification

1. Clean the surfaces to brazed by local filing

2. Wipe surfaces clean with a clean cloth wetted with degreasing solvent, acetone or alcohol

3. Flux the surfaces to be brazed with M 53303AA

4. Preplace a .003" thick x appropriate area piece of 75% Ag-28% Cu brazing alloy (PDS 16702DP-DQ) between the pieces to be brazed and clamp together

5. Furnace braze in argon or heat with oxyacetylene torch if oxidation of copper is not of concern. Brazing temperature is 1450-1470°F

6. Allow to cool

7. Remove flux residues by immersion in 3% by volume hydrochloric acid solution followed by thorough water rinsing

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3,000 H.P, 6-POLE MOTOR-BRAZING SPECIFICATION-CROSS CONNECTORS

6439A64

S.O.	SUB.
D.	1
T.P.G, 6-5-78	

Brazing Specification

1. Clean the copper surfaces to be brazed by mechanical abrasion with steel wool, file, or abrasive material such as Scotchbrite

2. Wipe surfaces with a clean cloth wetted with degreasing solvent, acetone or alcohol

3. Place a piece of .003" x appropriate area copper-silver-phosphorus brazing alloy (PDS 13402VJ) between the parts to be brazed

4. Clamp the joint area between the carbon blocks of a carbon block resistance brazing unit and apply power to heat and flow the brazing alloy. You may have to apply cooling to the nearby joint brazed at an earlier stage of manufacture (Drawing 2615C08) to prevent remelting of this previously made joint. Remelt temperature of this previously made joint is above 1440°F and the Cu-Ag-P brazing alloy used in the end connector will flow at about 1350°F. You may also get by with simply clamping the stator return conductor cross connector joints to prevent their opening up if the brazing alloy should remelt

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3,000 H.P, 6-POLE MOTOR-BRAZING SPECIFICATION-END CONNECTOR

6439A65

DIVISION

PLANT LOCATION

S.O.	SUB.
D.	1
PG. 6-5-78	

Brazing Specification

1. Degrease by solvent wiping with clean cloth or vapor degreasing

2. Brighten the copper surface by mechanical abrasion with steel wool, Scotchbrite or filing or by bright dipping in a solution containing (by volume) 55% sulfuric acid, 15% nitric acid, 0.5% hydrochloric acid, and balance water. A 10-20 second dip in the acid is sufficient followed by a water rinse, dry

3. Wipe surfaces to be brazed with a clean cloth dampened with acetone or alcohol, immediately prior to assembly for brazing

4. Preplace .003" thick x width and length as needed of Cu-15Ag-5P brazing alloy (PDS 13402VJ strip) between the copper tube and machined bar segments and fixture to hold in place during heating. No flux is needed

5. Assemble the tee on the tube and place a 1/16" wire diameter ring of the same brazing alloy (PDS 13430JA wire) around the assembly at the joint. No flux is needed

6. Heat in a furnace in an argon atmosphere to a temperature of 1340-1370°F and hold long enough for all parts to reach this temperature and achieve brazing alloy flow

7. Allow to cool in argon

8. Inspect

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3,000 H.P, 6-POLE MOTOR-BRAZING SPECIFICATION-MANIFOLDS

6439A66

DIVISION ________ PLANT LOCATION ________

S.O.	SUB.
D.	1
6-5-78	

Brazing Specification

1. Degrease by solvent wiping with clean cloth or vapor degreasing

2. Brighten the copper surface by mechanical abrasion with steel wool, Scotchbrite or filing or by bright dipping in a solution containing (by volume) 55% sulfuric acid, 15% nitric acid, 0.5% hydrochloric acid, and balance water. A 10-20 second dip in the acid is sufficient followed by a water rinse, dry

3. Wipe surfaces to be brazed with a clean cloth dampened with acetone or alcohol, immediately prior to assembly for brazing

4. Assemble the stack of .020" thick copper sheets and clamp between copper blocks about 1/4" further from the end than the desired length of braze. On the end with the extra copper block, fixture the block in position for brazing

5. Heat with oxyacetylene torch to about 1340-1370°F and face feed the joint area with copper-silver-phosphorus brazing alloy wire (PDS 13430JA)

6. Allow to cool, inspect

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3,000 H.P, 6-POLE MOTOR - BRAZING SPECIFICATION - RISER

6439A67

DIVISION

PLANT LOCATION

S.O.	SUB.
D.	1

Brazing Specification

1. Degrease by solvent wiping with clean cloth or vapor degreasing

2. Brighten the copper surface by mechanical abrasion with steel wool, Scotchbrite or filing or by bright dipping in a solution containing (by volume) 55% sulfuric acid, 15% nitric acid, 0.5% hydrochloric acid, and balance water. A 10 - 20 second dip in the acid is sufficient followed by a water rinse, dry

3. Wipe surfaces to be brazed with a clean cloth dampened with acetone or alcohol, immediately prior to assembly for brazing

4. Heat with oxyacetylene torch to about 1340-1370°F and face feed the joint area with copper-silver-phosphorus brazing alloy wire (PDS 13430JA)

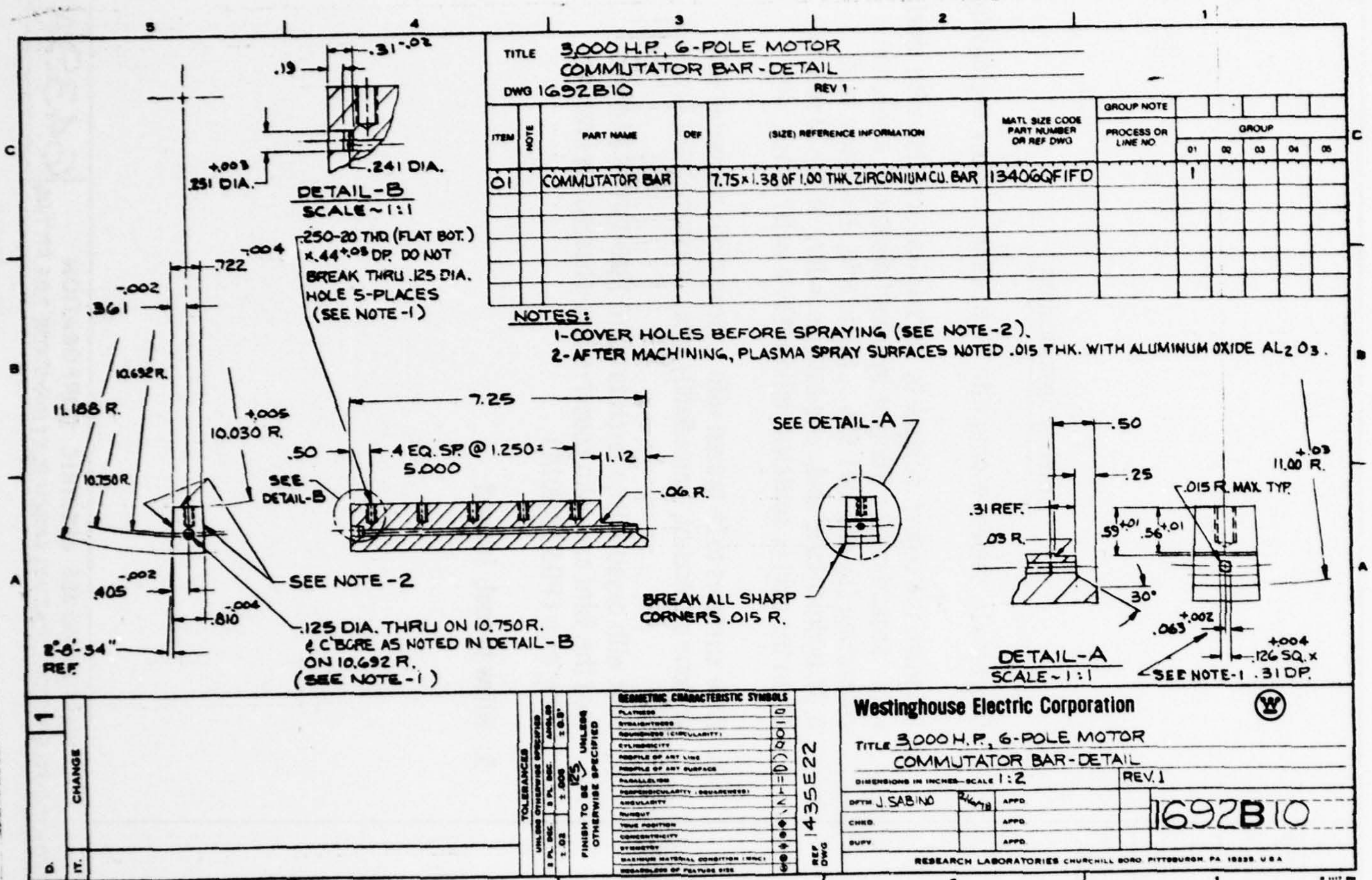
5. Allow to cool, inspect

WESTINGHOUSE ELECTRIC CORPORATION

TITLE 3,000 H.P. 6-POLE MOTOR-BRAZING SPECIFICATION-STATOR TUBE FITTING

6439A99

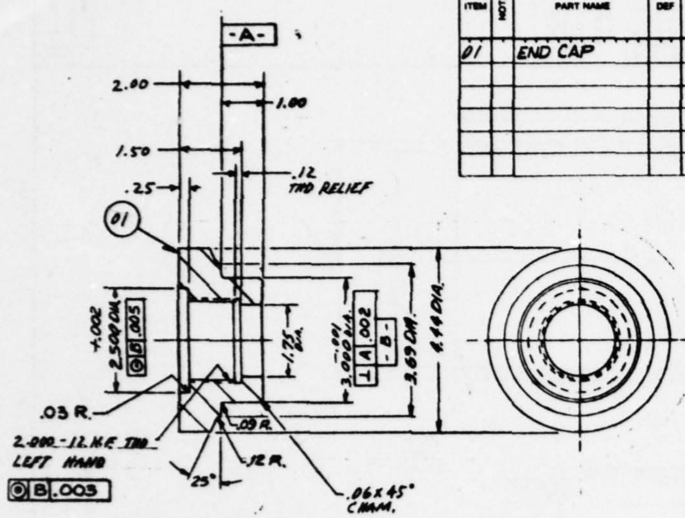
PLANT LOCATION


TITLE 3,000 H.P., 6-POLE MOTOR
COMMUTATOR BAR-DETAIL
DWG 1692B10
REV 1
ITEM
NOTE
PART NAME
DEF
(SIZE) REFERENCE INFORMATION
MATL SIZE CODE PART NUMBER OR REF DWG
GROUP NOTE
PROCESS OR LINE NO
GROUP
01
02
03
04
05
01
COMMUTATOR BAR
7.75 x 1.38 OF 1.00 THK. ZIRCONIUM CU. BAR
13406QFIFD
1
NOTES:
1-COVER HOLES BEFORE SPRAYING (SEE NOTE-2).
2-AFTER MACHINING, PLASMA SPRAY SURFACES NOTED .015 THK. WITH ALUMINUM OXIDE AL2 O3.
DETAIL-B
SCALE~1:1
.250-20 THD. (FLAT BOT.) x.44 DP. DO NOT BREAK THRU .125 DIA. HOLE 5-PLACES (SEE NOTE-1)
.241 DIA.
.251 DIA.
7.25
4 EQ. SP. @ 1.250 = 5.000
1.12
.06 R.
SEE DETAIL-B
10.030 R.
10.692 R.
11.188 R.
10.750 R.
SEE NOTE-2
.125 DIA. THRU ON 10.750 R. & C'BORE AS NOTED IN DETAIL-B ON 10.692 R. (SEE NOTE-1)
2°-8'-34" REF.
SEE DETAIL-A
BREAK ALL SHARP CORNERS .015 R.
.31 REF.
.03 R.
.015 R. MAX. TYP.
11.00 R.
DETAIL-A
SCALE~1:1
SEE NOTE-1 .31 DP.
.126 SQ. x
CHANGE
TOLERANCES UNLESS OTHERWISE SPECIFIED
FINISH TO BE 125 UNLESS OTHERWISE SPECIFIED
GEOMETRIC CHARACTERISTIC SYMBOLS
REF DWG 1435E22
Westinghouse Electric Corporation
TITLE 3,000 H.P., 6-POLE MOTOR
COMMUTATOR BAR-DETAIL
DIMENSIONS IN INCHES—SCALE 1:2
REV. 1
DFTM J. SABINO
CHKD
SUPV
APPD.
1692B10
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

TITLE 3,000 H.P., 6 POLE MOTOR
END CAP-ROTOR COOLING WATER END-DETAIL

DWG 1692B11 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		END CAP		2.25 LG. OF 5.000 DIA 304 SST. ROD	R+D Stock No. 5701-0101		1				



TOLERANCES UNLESS OTHERWISE SPECIFIED
2 PL. DEC ± .02 | 3 PL. DEC ± .005 | ANGLES ± 0.5°

FINISH TO BE 125 ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS: FLATNESS; STRAIGHTNESS; ROUNDNESS (CIRCULARITY); CYLINDRICITY; PROFILE OF ANY LINE; PROFILE OF ANY SURFACE; PARALLELISM; PERPENDICULARITY (SQUARENESS); ANGULARITY; RUNOUT; TRUE POSITION; CONCENTRICITY; SYMMETRY; MAXIMUM MATERIAL CONDITION (MMC); REGARDLESS OF FEATURE SIZE

REF DWG 1435E21

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR
END CAP-ROTOR COOLING WATER END-DETAIL

DIMENSIONS IN INCHES—SCALE 1:2 | REV. 1

DFTM D. STAPINSKI 10/14/77 | APPD L. Kowalewski 6-19-78

CHKD | APPD

SUPV | APPD

1692B11

RESEARCH LABORATORIES CHURCHILL BORO, PITTSBURGH, PA 15235, U.S.A.

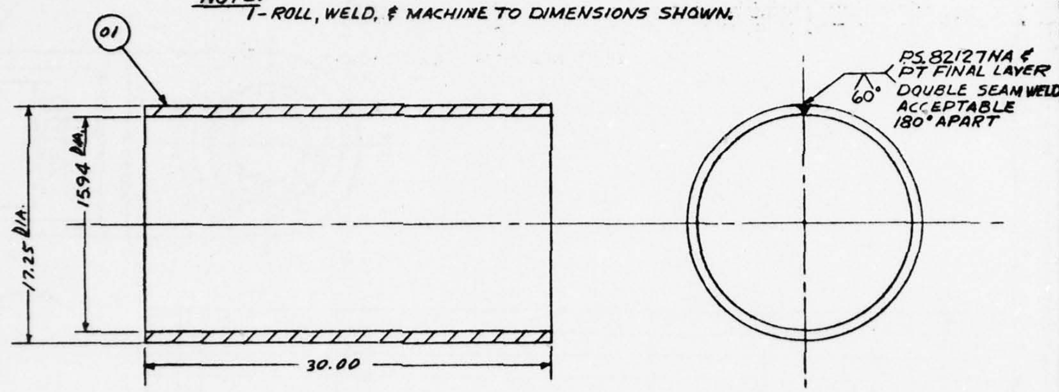
CHANGE | IT.

A- BASIS OF PURCHASE
- 5.1.1 FOR QUANTITY SEE PURCHASE ORDER
- 5.1.2 STAINLESS STEEL
- 5.1.3 PLATE
- 5.1.4 SEE DRAWING FOR DIMENSIONS
- 5.1.5 TYPE 304
- 5.1.6 NOT APPLICABLE
- 5.1.7 MECHANICAL PROPERTIES PER SECTION 9
- 5.1.8 NOT APPLICABLE
- 5.1.9 ASTM A-240-75 & TYPE 304
- 5.1.10 NOT REQUIRED

TITLE 3,000 H.P., 6 POLE MOTOR
BAFFLE TUBE - ROTOR COOLING - ROLL, WELD, MACH.
DWG 1692B12 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	TUBING		ROLL FROM SST. PL			1				

NOTE:
1- ROLL, WELD, & MACHINE TO DIMENSIONS SHOWN.



TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL. DEC ± .06; 3 PL. DEC ± .005; ANGLES ± .01
FINISH TO BE 250 UNLESS OTHERWISE SPECIFIED

REF DWG 8522D81

Westinghouse Electric Corporation

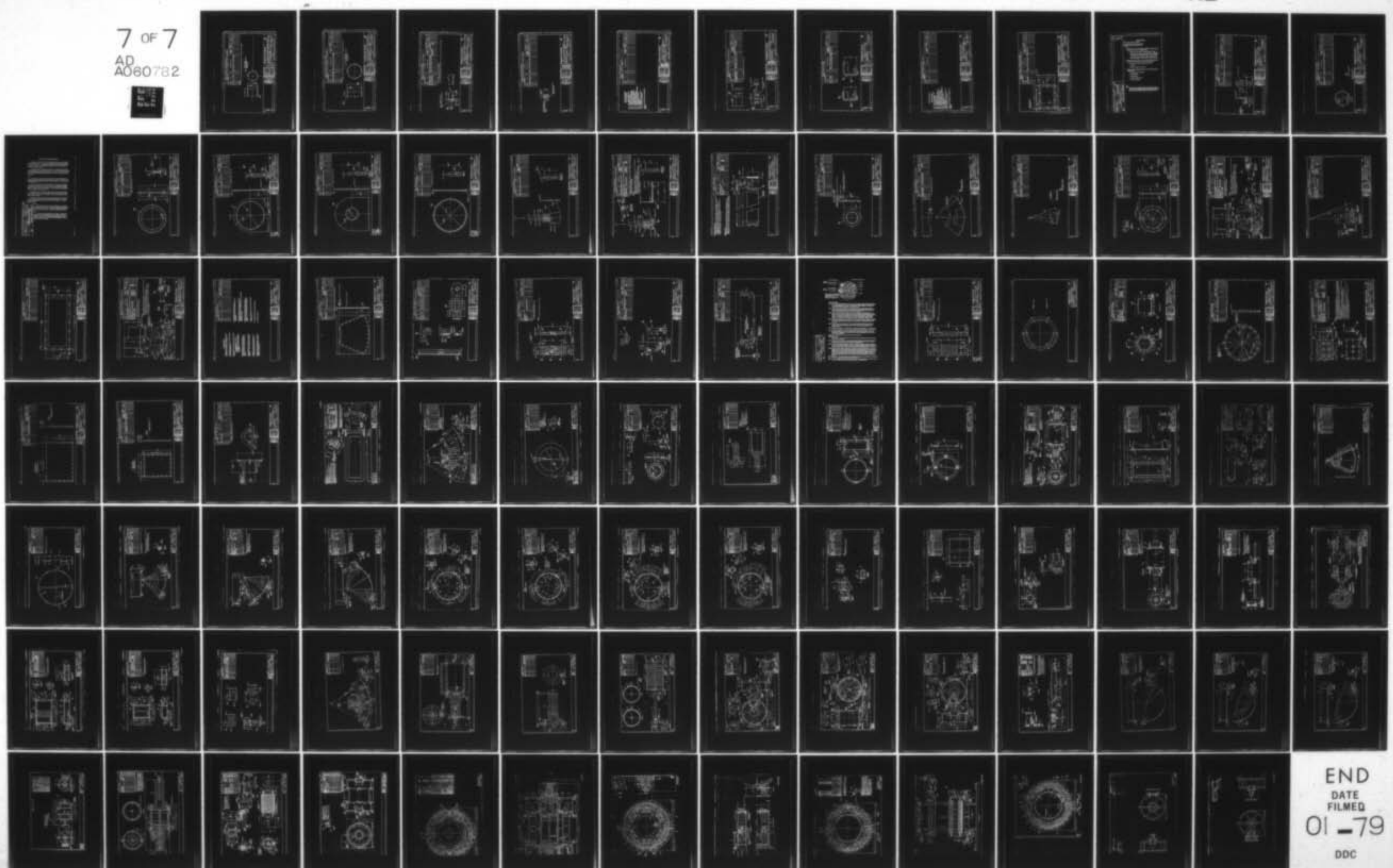
TITLE 3,000 H.P., 6 POLE MOTOR
BAFFLE TUBE - ROTOR COOLING - ROLL, WELD, MACH.
DIMENSIONS IN INCHES—SCALE 1:6 REV. 1
DFTM D. STAPINSKI APPD C. Heathcote 11-17-77
CHKD APPD
SUPV. APPD
1692B12

RESEARCH LABORATORIES CHURCHILL BORO, PITTSBURGH, PA 15235 U.S.A.

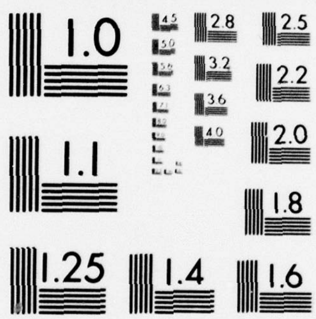
AD-A060 782 WESTINGHOUSE RESEARCH AND DEVELOPMENT CENTER PITTSBU--ETC F/G 9/3
SEGMAG MACHINES FOR MARINE ELECTRICAL PROPULSION SYSTEMS. APPEN--ETC(U)
SEP 78 N00014-77-C-0307

UNCLASSIFIED NL

7 OF 7
AD
A060782



END
DATE
FILMED
01 -79
DDC



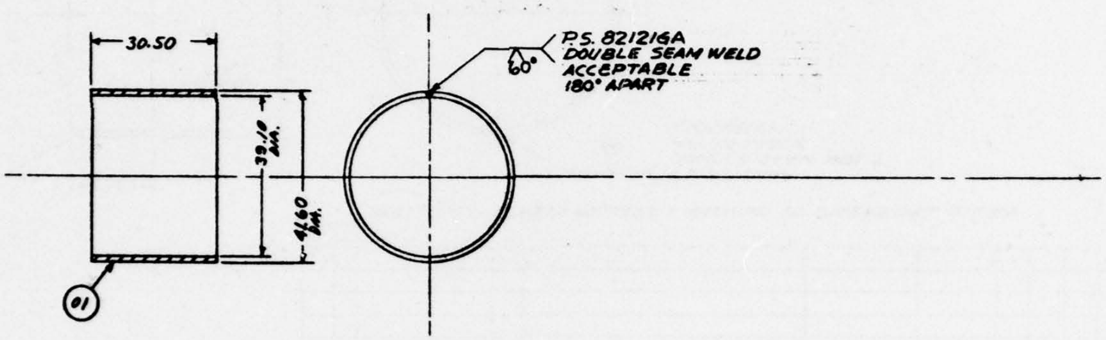
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TITLE 3,000 H.P., 6 POLE MOTOR - STATOR
SHELL - STATOR HOUSING - CENTER - ROLL, WELD, MACH.

DWG 1692B17 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		HSG. TUBE		ROLL FROM STL. PL. ASTM-A36			1				

NOTE:
1 - ROLL, WELD, STRESS RELIEVE & MACHINE TO DIMENSIONS SHOWN.



Westinghouse Electric Corporation

TITLE 3,000 H.P. 6 POLE MOTOR - STATOR
SHELL-STATOR HOUSING - CENTER - ROLL, WELD, MACH.

DIMENSIONS IN INCHES—SCALE 1:20

DFTR. R. STANISKI — CHKD. — SUPV. — APPD.

1692B17

REF DWG 639F490

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

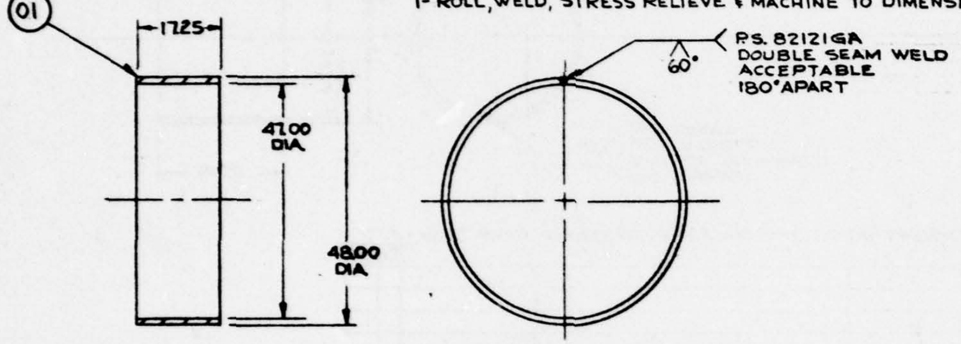
CHANGE

RESEARCH LABORATORIES CHURCHILL BORO, PITTSBURGH, PA. 15235, U.S.A.

TITLE 3,000 H.P., 6 POLE MOTOR-STATOR
SHELL-STATOR HSG-END-ROLL, WELD, MACH.
DWG 1692B22 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01		END HSG TUBE		ROLL FROM STL. PL. ASTM-A36			1				

NOTE:
1- ROLL, WELD, STRESS RELIEVE & MACHINE TO DIMENSIONS SHOWN.



TOLERANCES	GEOMETRIC CHARACTERISTIC SYMBOLS
UNLESS OTHERWISE SPECIFIED	
FINISH TO BE 250 UNLESS OTHERWISE SPECIFIED	

REF DWG 639F489, 639F492

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR-STATOR
SHELL-STATOR HSG-END-ROLL, WELD, MACH.
REV 1
DIMENSIONS IN INCHES—SCALE ~
DFTR T. GRADISEK 11-3-77 APPD [signature] 11-18-77
CHKD APPD
SUPV APPD
1692B22

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH, PA. 15235 U.S.A.

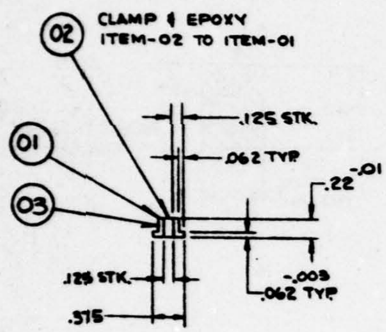
CHANGE	
1	

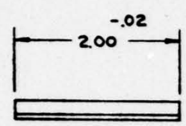
TITLE 3,000 H.P., 6-POLE MOTOR
WEDGE-RETURN CONDUCTOR-LAMINATION

DWG 1692B46 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO.	GROUP 01	02	03	04	05
						GROUP NOTE	A/C				
01	B	SIDE STRIP		.125 x .500 x .250 LG. RECT. STL. BAR		AISI M1020	2				
02		INSULATOR		2.50 x .38 OF .125 THK. MICARTA	PDS44165ER		1				
03		EPOXY RESIN			PDS53841FD		[illegible]				

A- PRECURE 160° C FOR 16 HOURS.
B- J.T. RYERSON & SON INC., PGH., PA.
C- THIS ITEM MAY BE MADE IN LONGER LENGTH. THEN CUT TO LENGTH SHOWN.





TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE 125 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG 639F493

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
WEDGE-RETURN CONDUCTOR-LAMINATION

DIMENSIONS IN INCHES—SCALE 1:1

DFTR T. GRADISEK 6-29-78 APPD [signature] 6-29-78

CHKD APPD

SUPV APPD

1692B46

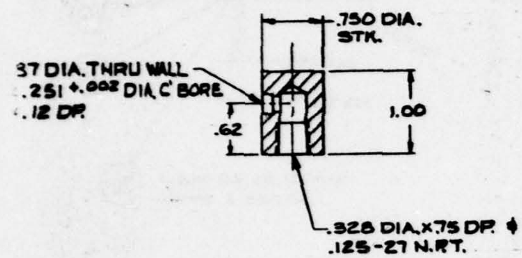
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH, PA 15235 U.S.A.

CHANGE

TITLE 3,000 H.P., 6-POLE MOTOR
COOLING H2O BLOCK-END CONNECTORS- STATOR

DWG 1692B69 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG R&D STOCK NR.	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		FITTING BLOCK		1.25 LG. × .750 DIA. CU. ROD	5404-0101	ASTM B-187	1				



CHANGE

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE 125 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF 2916C08 2916C24
DWG 2916C36 8632D16
8632D26 8632D30
A127408 A127496 1692B57

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
COOLING H2O BLOCK-END CONNECTORS - STATOR

DIMENSIONS IN INCHES—SCALE 1:1

REV. 1

DFTN J. SABINO

CHKD

SUPV

APPD

APPD

APPD

1692B69

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA. 15235 U.S.A.

TITLE 3,000 H.P., 6 POLE MOTOR
MATERIAL ORDERING INFORMATION
DWG 1693B52 REV 1

Copper per ASTM B 152-77

Ordering Information

3.1.1. For quantity see purchase order
3.1.2. Copper UNS No C10100
3.1.3. Temper H03 - three quarters hard
3.1.4. See detail drawing for dimensions.
3.1.5. Rounded corner edges are required
3.1.6. Resistivity testing is required
3.1.7. Embrittlement testing is required
3.1.8. Material to be furnished in straight lengths
3.1.9. See detail drawing for length
3.1.10. Not applicable
3.1.11. Certification of testing is required
3.1.12. Test reports are not required

Material per PDS 13406CB may be supplied as an alternate.

ITEM	NOTE	PART NAME	DEP	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE: PROCESS OR LINE NO.	GROUP 01	02	03	04	05

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR
MATERIAL ORDERING INFORMATION

DIMENSIONS IN INCHES—SCALE

REV 1

DFTN D. STRAYMORE

APPD

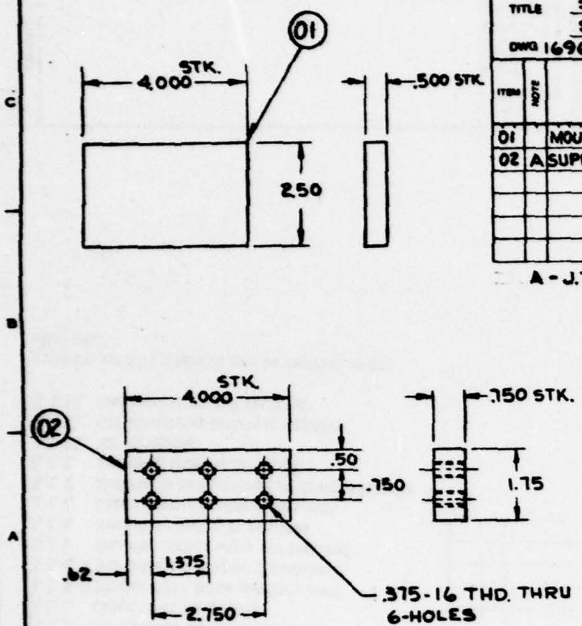
CHKD.

SUPV.

1693B52

RESEARCH LABORATORIES CHURCHILL BORO, PITTSBURGH, PA. 15235, U.S.A.

CHANGE



TITLE 3,000 H.P., 6-POLE MOTOR
SHUNT MOUNTING & SUPPORT BLOCK DETAILS
DWG 1696B82 REV. 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG R&D STOCK NO	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		MOUNTING BLOCK		.500 x 4.000 x 3.00 LG. RECT. CU. BAR	7008-0801	ASTM B-187	1				
02	A	SUPPORT BLOCK		.750 x 4.000 x 2.25 LG. RECT. SST BAR		TYPE 304	1				

A - J.T. RYERSON & SON INC., PGH., PA.

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
SHUNT MOUNTING & SUPPORT BLOCK DETAILS

DIMENSIONS IN INCHES—SCALE 1:2 REV-1

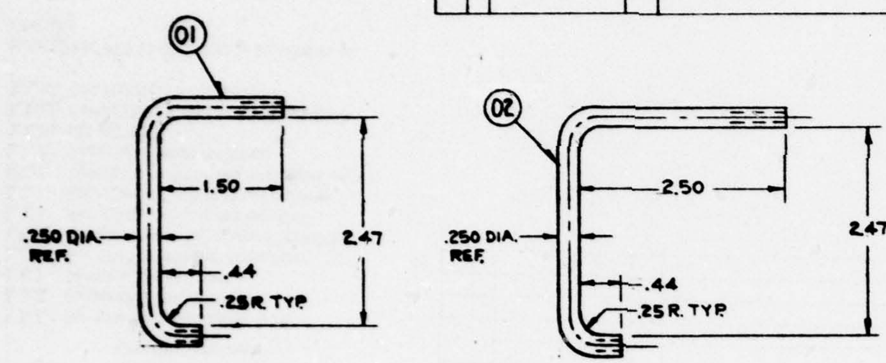
DFTM T. GRADISEK 4-70

1696B82

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

TITLE 3,000 H.P., 6-POLE MOTOR
TUBING DETAILS-ROTOR
DWG 1696B84 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STOCK NO.	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		TUBE		5.25 OF .125 I.D. x .250 O.D. CU. TUBING	7312-0101		1				
02		TUBE		6.25 OF .125 I.D. x .250 O.D. CU. TUBING	7312-0101		1				



CHANGE

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG 1435E22

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
TUBING DETAILS-ROTOR
DIMENSIONS IN INCHES—SCALE 1:1
REV-1

DFTM T. GRADISEK

1696B84

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA 15235 U.S.A.

TITLE 3,000 H.P., 6-POLE MOTOR
MATERIAL ORDERING INFORMATION
DWG. 1697B05 REV. 1

ITEM	NOTE	PART NAME	QTY	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05

Copper per ASTM B 152-77

Ordering Information

3.1.1. For quantity see purchase order
3.1.2. Copper UNS No C12500
3.1.3 Temper H02 - half hard
3.1.4. See detail drawing for dimensions
3.1.5. Rounded corner edges are not required
3.1.6 Resistivity testing is not required
3.1.7. Embrittlement testing is not required
3.1.8. Material to be furnished in straight lengths
3.1.9. See detail drawing for length
3.1.10. Not applicable
3.1.11. Certification of testing is not required
3.1.12. Test reports are not required

Material per PDS 13406CC may be supplied as an alternate

CHANGE 1

TOLERANCES UNLESS OTHERWISE SPECIFIED

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG 8522D39 8522D40 8522D47 8522D48

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
MATERIAL ORDERING INFORMATION
REV. 1

DFTR. J. SABINO

CHKD. APPD.

SUPV. APPD.

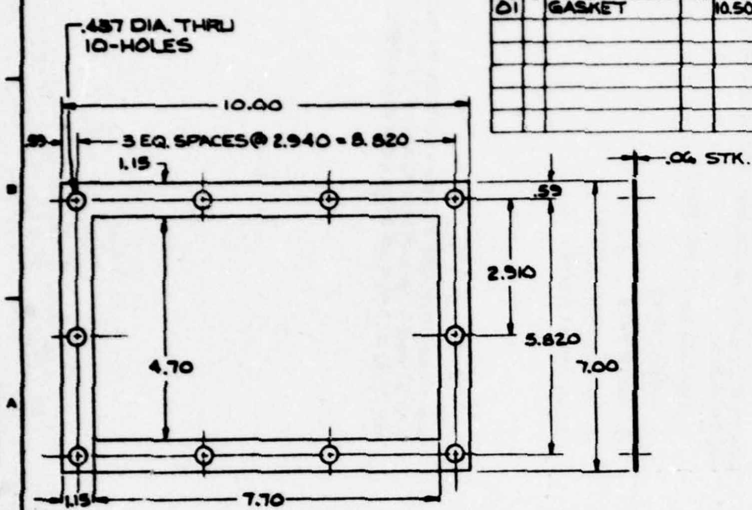
1697B05

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA. 15235 U.S.A.

TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.
STUFFING TUBE MTG. PLATE GASKET-TERM. BOX

DWG 1697B51 REV 1

ITEM	NOTE	PART NAME	QTY	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		GASKET		10.50 X 7.50 OF .06 THK. BUNA 'N' SH.	PDS4535IEL		1				



TOLERANCES UNLESS OTHERWISE SPECIFIED		
2 PL. DEC. ± .03	3 PL. DEC. ± .005	ANGLES ± 0.5°

FINISH TO BE √ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG 1289J56
1289J53

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.
STUFFING TUBE MTG. PLATE GASKET-TERM. BOX

DIMENSIONS IN INCHES—SCALE N.T.S. REV. 1

DFTR. J. SABINO
CHKD.
SUPV.
APPD
APPD
APPD

1697B51

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH PA 15235 U.S.A.

CHANGE

S.O.
D.
1

IT.	CHANGE

Cleaning Procedure

Cleaning shall consist of three steps:

A. Cleaning with acetone or alcohol followed by
B. Flushing with demineralized water, then
C. Drying

A. Depending on size, shape, accessability, and state of completion, parts may be cleaned by any or all of the following methods:

1. Wiping with lint free cloths saturated with acetone or alcohol
2. Total immersion in acetone or alcohol provided such immersion will not damage any of the component materials - such as insulation
3. Flushing, pumping, or circulating acetone or alcohol through inaccessable crevices, drilled holes and through pipes and tubes

B. Following cleaning, with acetone or alcohol, parts must be cleaned again with demineralized water by any or all of the following methods:

1. Wiping with saturated or moistened lint free cloths
2. Immersion
3. Flushing, pumping, or circulating

C. Following the demineralized water bath, parts may be dried by any of the following methods

1. Wiping with dry lint free cloths
2. Forced air drying
3. Vacuum drying
4. Heating or baking at 150°F
5. Dry nitrogen surging

Note:

When cleaning, hydrostatic and helium leak testing are required by the detail drawing, hydrostatic testing can be performed in conjunction with step B, and helium leak testing may be performed after step C

REF DWG

Westinghouse Electric Corporation

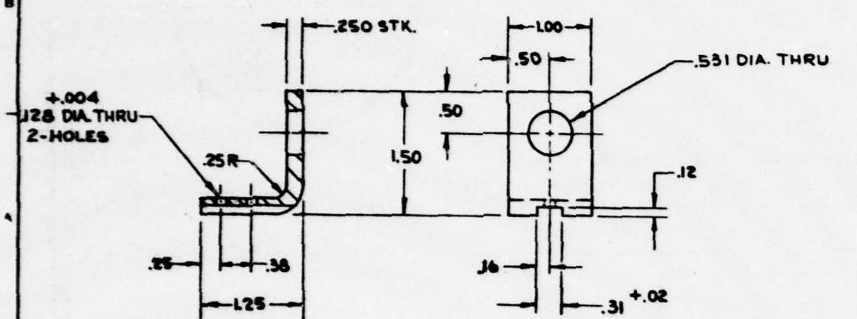
TITLE 3,000 H.P. 6-POLE MOTOR & 4 POLE GEN.
CLEANING PROCEDURE
REV 1

1697B64

RESEARCH LABORATORIES

TITLE 3,000 H.P., 6-POLE MOTOR
TERMINAL LUG-FIELD COIL
DWG 1698B20 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		TERMINAL LUG	DWG	3.25 x 1.25 OF .250 THK. CU.	1693B52						



TOLERANCES UNLESS OTHERWISE SPECIFIED
FINISH TO BE 125 UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS

REF DWG 1289J56

Westinghouse Electric Corporation

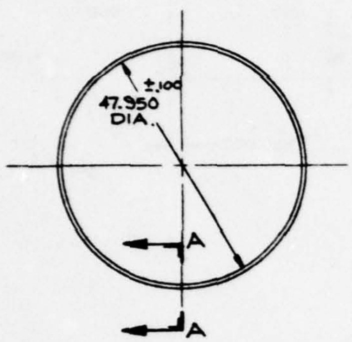
TITLE 3,000 H.P., 6-POLE MOTOR
TERMINAL LUG-FIELD COIL
DIMENSIONS IN INCHES—SCALE 1:1 REV 1
DFTR T. GRADISEK
CHKD
SUPV.
APPD
1698B20
RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH PA 15235 U.S.A.

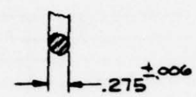
CHANGE

TITLE 3,000 H.P., 6-POLE MOTOR
"O" RING DETAIL-STATOR HOUSING
DWG 1698B23 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	"O" RING	BOS.	.250 DIA. NOM. CROSS SECTION	BUNA-"N"		1				

A-SUPPLIED BY PARKER SEAL CO. 2360 PALUMBO DRIVE LEXINGTON, KY. 40509





SECTION A-A

TOLERANCES UNLESS OTHERWISE SPECIFIED: 2 PL. DEC ±.02; 3 PL. DEC ±.005; ANGLES ±0.5°

FINISH TO BE ✓ UNLESS OTHERWISE SPECIFIED

GEOMETRIC CHARACTERISTIC SYMBOLS: FLATNESS; STRAIGHTNESS; ROUNDNESS (CIRCULARITY); CYLINDRICITY; PROFILE OF ANY LINE; PROFILE OF ANY SURFACE; PARALLELISM; PERPENDICULARITY (SQUARENESS); ANGULARITY; RUNOUT; TRUE POSITION; CONCENTRICITY; SYMMETRY; MAXIMUM MATERIAL CONDITION (MMC); REGARDLESS OF FEATURE SIZE

REF DWG 1289J56

CHANGE 1

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
"O" RING DETAIL-STATOR HOUSING

DIMENSIONS IN INCHES—SCALE N.T.S. REV. 1

DRTN J. SABINO | APPD
CHKD | APPD
SUPV | APPD

1698B23

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA. 15235 U.S.A.

DIELECTRIC TESTS FOR SEGMAG ROTOR BARS

The following series of dielectric tests is intended to qualify the rotor bars of the 3000 hp SEGMAG motor and generators. Consultation on appropriate tests to perform was obtained from Dr. T. W. Dakin and Dr. A. I. Bennett of the Electrical Performance of Insulating Materials Department. In addition the relevant Military Specification, MIL-G-18473A (SHIPS), was checked to determine required tests.

The testing will be done at three stages of manufacture. The isolated bars will be tested following the completion of rotor bar fabrication (test A). The rotor and commutator bar assembly will be connected after completion of soldering together the circuit (test B). Finally, the complete rotor winding will be tested after assembly of the rotor (test C). The details of these three tests follows.

TEST A

First, several (2 or 3 each for motor and generator) bars will be tested to destruction to determine the average breakdown strength of the insulation. Sixty cycle, ac voltage will he used. The RMS value of the average breakdown voltage will be designated V_{BD}. This is expected to be in the range 10-15 kV.

The second part of this test will be to test the remainder of the bars at an RMS voltage V_A and that $V_{BD} > V_A > 2000$ volts. This should be chosen to be considerably below breakdown, in order not to inadvertently damage any of the bars, but still well above the final test voltage, 2000 volts. A probable value for V_A will be 5000 volts. Any bar in which the insulation breaks down at this level will, of course, be rejected.

As an additional check, the corona onset voltage will be recorded for each bar during this test. An average value of this corona onset voltage will be determined, and any bar deviating significantly from this average corona onset voltage (± 30% ?) will be regarded with suspicion, *pending further examination.*

The method of carrying out this test will be to place aluminum bars on the top and bottom of the rotor bars, terminating .75 inch from the ends of the insulated section. The voltage will then be applied between these aluminum bars and the rotor bar copper. The test will be done by Dr. Bennett.

TEST B

A second ac voltage, V_B, will be chosen such that $V_A > V_B > 2000$ volts. A probable value of V_B is 3500 volts. This will be applied between the commutator bar and the rotor iron (ground). Any evidence of incipient breakdown during this test will be cause for rejection of the rotor and commutator bar assembly.

TEST C

This is the test required by MIL Spec. MIL-G-18473A. A 60 cycle RMS voltage of 2000 volts will be applied between the rotor winding and the rotor iron (ground). This test will follow the satisfactory completion of the insulation resistance measurement. All motor bars will be shorted together for this test. Test duration will be sixty seconds.

Westinghouse Electric Corporation

TITLE 3000 HP, 4 Pole Gen & 6 Pole Motor
Rotor-Dielectric Test for Conductor Bars

DIMENSIONS IN INCHES—SCALE | Rev 1

DFTR | 7-17-78 | APPD
CHKD D Spurbeck | 7-17-78 | APPD
APPD

1698B66

REF. DWG.

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA U.S.A.

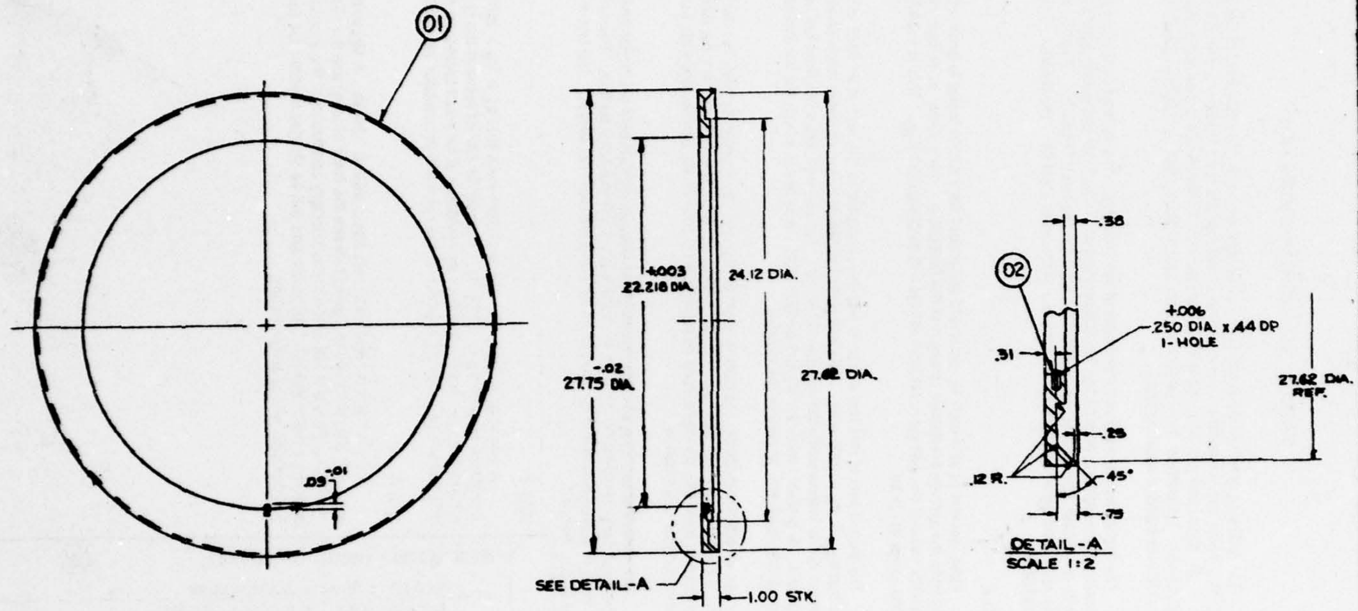
TITLE 3,000 H.P., 6 POLE MOTOR

COVER-ROTOR CONDUCTOR COOLING TUBES

DWG 2614C74 REV 1

ITEM	NOTE	PART NAME	DEP	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STOCK No.	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		COVER PLATE		30.25×30.25×1.000 THK. MICARTA PL GRADE # 281	8102-0101		1				
02	A	ROLL PIN		.250 DIA.×.50 LG CAT# 99-048-250-0500			1				

A - ELASTIC STOP NUT DIV. AMERACE ESNA CORP., 2330 VAUXHALL ROAD UNION, NEW JERSEY 07083.



CHANGE

REF DWG 1435E22

UNLESS OTHERWISE SPECIFIED

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR

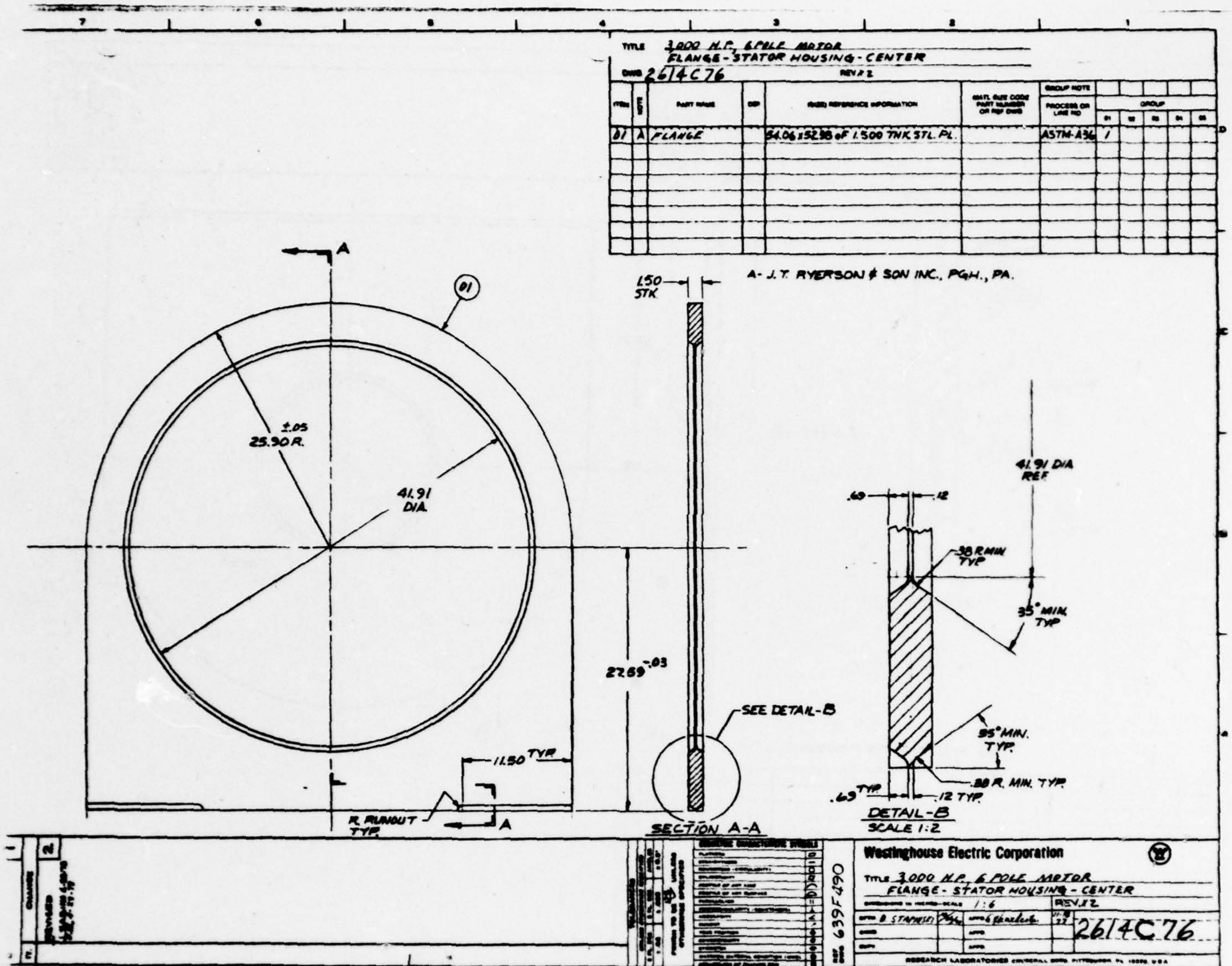
COVER-ROTOR CONDUCTOR COOLING TUBES

SCALE 1:4 REV 1

T. GRADISEK

2614C74

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA. 15235 U.S.A.

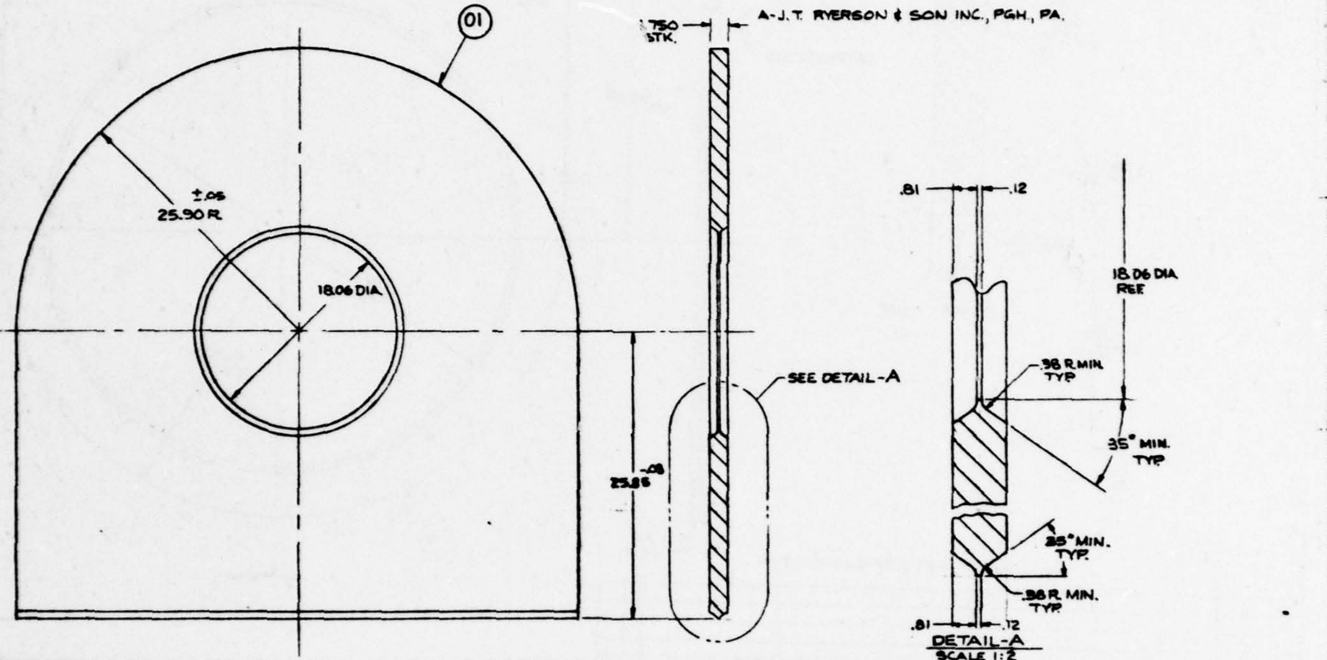


TITLE 3000 H.P. 6 POLE MOTOR
FLANGE - STATOR HOUSING - CENTER
DWG 2614C76
REV # 2
01 A FLANGE 54.06 x 52.98 of 1.500 THK STL. PL. ASTM-A36 1
A- J.T. RYERSON & SON INC., PGH., PA.
01
A
25.90 R. ±.05
41.91 DIA
1.50 STK
27.69 -.03
11.50 TYP
R. RUNOUT TYP
SEE DETAIL-B
SECTION A-A
41.91 DIA REF
.69
.12
.38 R MIN TYP
35° MIN. TYP
35° MIN. TYP.
.38 R. MIN. TYP.
.69 TYP
.12 TYP.
DETAIL-B
SCALE 1:2
Westinghouse Electric Corporation
TITLE 3000 H.P. 6 POLE MOTOR
FLANGE - STATOR HOUSING - CENTER
SCALE 1:6
REV. # 2
2614C76
639F490

TITLE 3,000 H.P., 6 POLE MOTOR
FLANGE-STATOR HOUSING-ENDS
DWG 2614C88 REV #3

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	01	02	03	04	05
01	A	FLANGE		52.38x52.38 of 1.750 THK. STL. PL		ASTM-A36	1				

A-J.T. RYERSON & SON INC., PGH., PA.



Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR
FLANGE-STATOR HOUSING-ENDS
SCALE 1:6 REV #3
T GRADISEK
2614C88

REF DWG 639F489
639F492

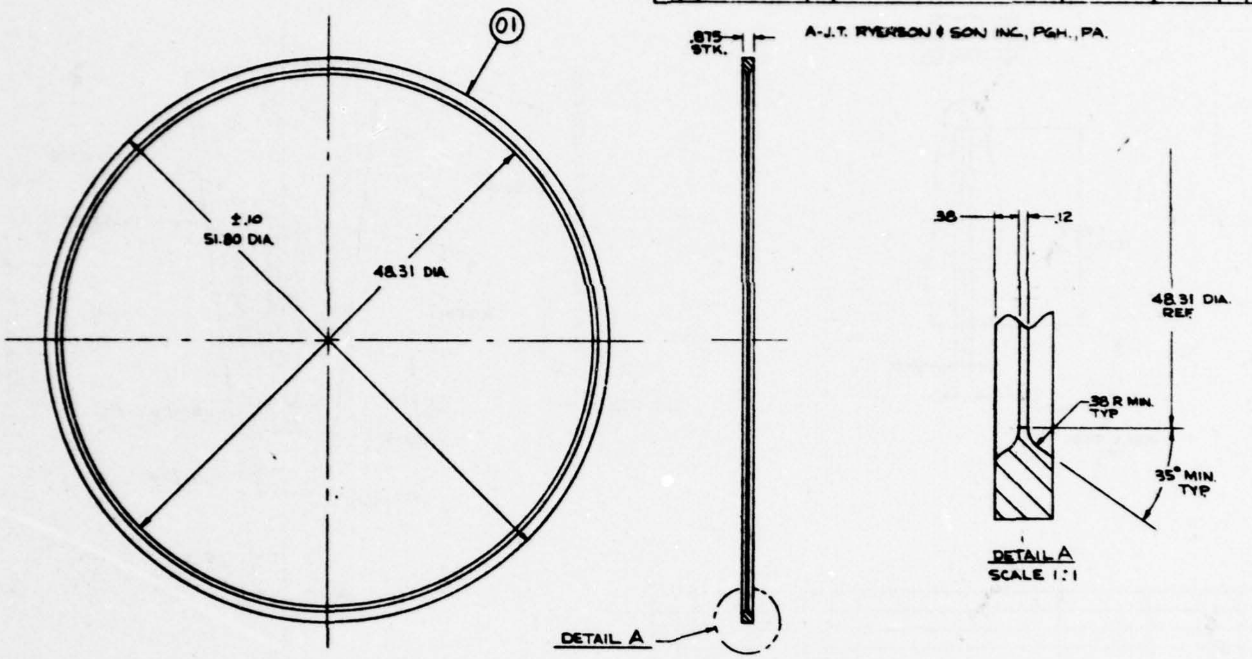
CHANGE
2 REVISED
3 WAS
DWG 6-1-76

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

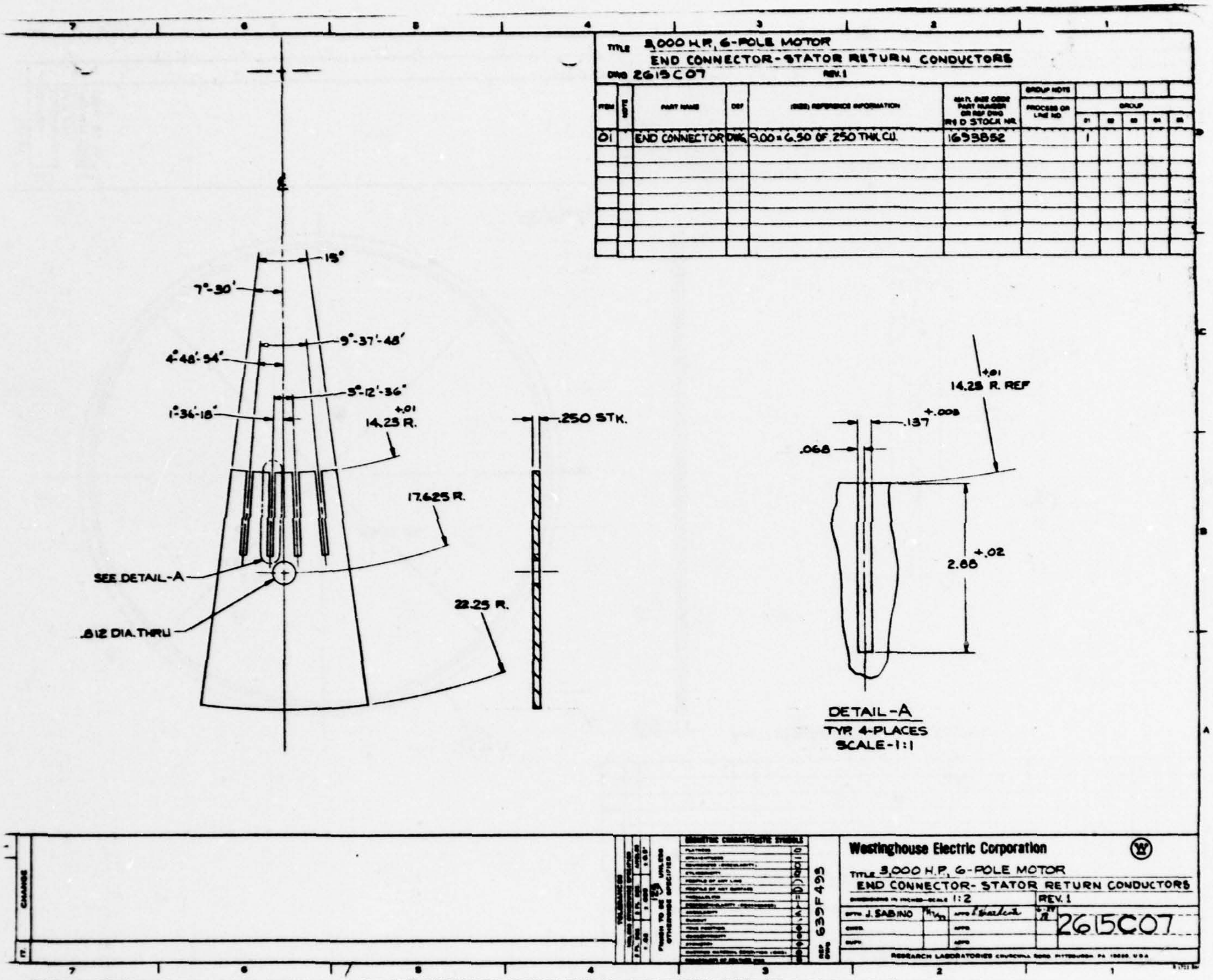
TITLE 3,000 H.P. 6 POLE MOTOR
FLANGE-STATOR HOUSING-ENDS
DWG 2614C89 REV #3

ITEM	NOTE	PART NAME	REF	USED REFERENCE INFORMATION	MAT'L DIAG CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	G1	G2	G3	G4	G5
01	A	FLANGE		52.38x52.98 of .875 THK. STL. PL.		ASTM-A36	1				

A-J.T. RYERSON & SON INC., PGH., PA.



Westinghouse Electric Corporation
TITLE 3,000 HP, 6 POLE MOTOR
FLANGE-STATOR HOUSING-ENDS
SCALE 1:6 REV #3
T. BRADISEK
2614C89
REF DWG 639F489 639F492
REVISED
13.0' WAS 13.5'
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA


TITLE 3,000 H.P. 6-POLE MOTOR
END CONNECTOR-STATOR RETURN CONDUCTORS
DWG 2615C07 REV.1
01 END CONNECTOR DWG. 3.00 x 6.50 OF .250 THK CU. 1693852
15°
7°-30'
9°-37'-48'
4°-48'-54'
3°-12'-36"
1°-36'-18"
+.01 14.25 R.
17.625 R.
SEE DETAIL-A
.812 DIA. THRU
22.25 R.
.250 STK.
+.01 14.25 R. REF
+.008 .137
.068
+.02 2.88
DETAIL-A
TYP. 4-PLACES
SCALE-1:1
Westinghouse Electric Corporation
TITLE 3,000 H.P. 6-POLE MOTOR
END CONNECTOR-STATOR RETURN CONDUCTORS
1:2
REV. 1
J. SABINO
2615C07
639F495

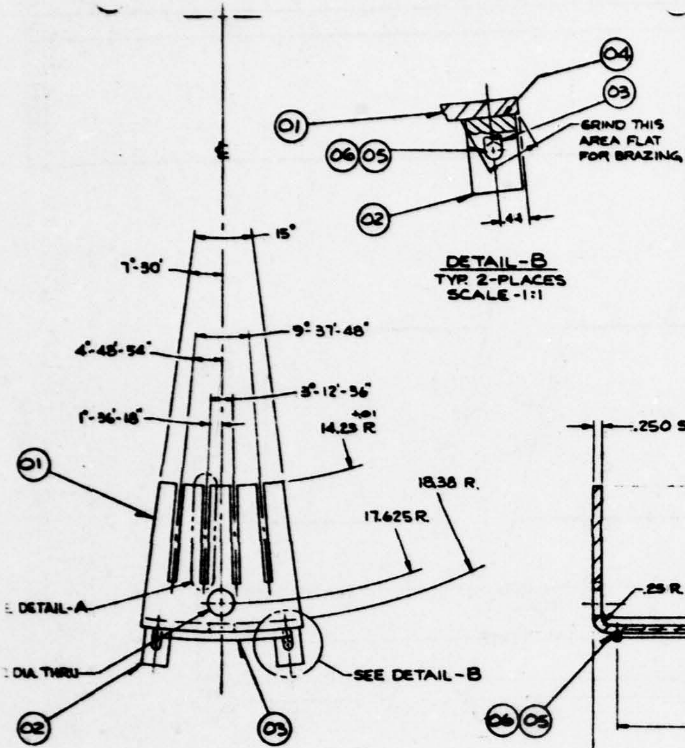
TITLE 3,000 H.P., 6-POLE MOTOR
END CONNECTOR-RETURN CONDUCTORS TO BRUSHES
DWG 2615C08 REV 1

ITEM	NOTE	PART NAME		REFERENCE INFORMATION	PART NUMBER OR REF DWG	PROCESS OR USE NO.	GROUP
01		END CONNECTOR	DWG	16.00 x 6.00 OF .250 THK. CU.	1693852		1
02		FITTING BLOCK	DWG		1692B69H01		2
03	A	COOLING TUBE		.250 OD x .032 WALL SOFT CU. TUBING		ASTM B-75	1
04		BRAZING SPEC.	DWG		6439A64		AR
05		SOFT SOLDER		60% TIN, 40% LEAD	PD517630AG		AR
06		SOLDERING FLUX		ALCOHOL & ROSIN	M5S301AA		AR

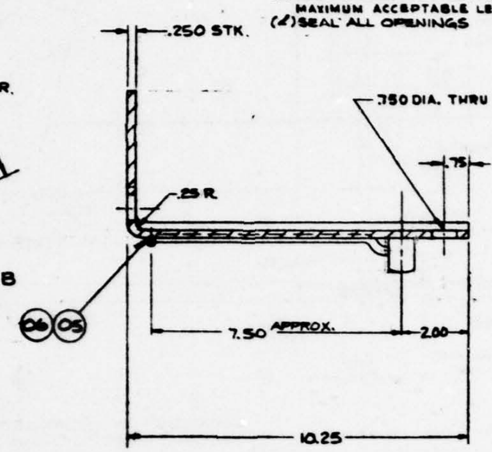
A-LENGTH AS REQ'D. & SHAPE OF TUBING TO FOLLOW CONTOUR OF END CONNECTOR LEAD (ITEM-01) AS SHOWN.
B-WILLIAMS & CO. INC. PGH., PA. 15233.

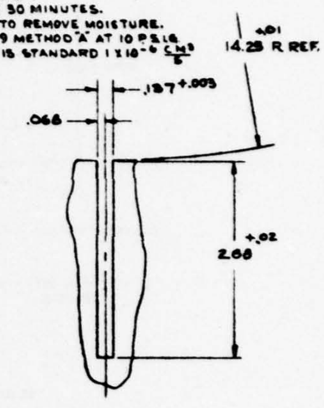
NOTES:

1-CLEAN INSIDE OF FITTING BLOCKS (ITEM-02) & COOLING TUBE (ITEM-03) PER DRAWING 1697B64 & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 P.S.I. FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST PER ASTM B-499 METHOD "A" AT 10 P.S.I.G. MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD $1 \times 10^{-6} \frac{CM^3}{S}$
(d) SEAL ALL OPENINGS



DETAIL-B
TYP. 2-PLACES
SCALE-1:1





DETAIL-A
TYP 4-PLACES
SCALE-1:1

Westinghouse Electric Corporation
TITLE 3,000 H.P., 6-POLE MOTOR
END CONNECTOR-RETURN CONDUCTORS TO BRUSHES
SCALE 1:2 REV. 1
T. GRADISEK
2615C08
REF DWG 639F495

INSULATION PROCEDURE:

1- GROUND WALL INSULATION TO MAX. DIMENSIONS SHOWN. INSULATION CONSISTS OF LAYERS OF KAPTON TAPE PER PDS 447898A HALF LAPPED, PLUS A FINAL LAYER OF .005 THK GLASS TAPE PER PDS41514CL HALF LAPPED.

2- TO COMPLETE, PERFORM TWO VACUUM IMPREGNATION CYCLES USING M5384IFD RESIN. APPLY TWO DIP COATS OF M5384IFD & GELL EACH COAT AT 135°C. THEN BAKE AT 160 C. FOR 16 HOURS.

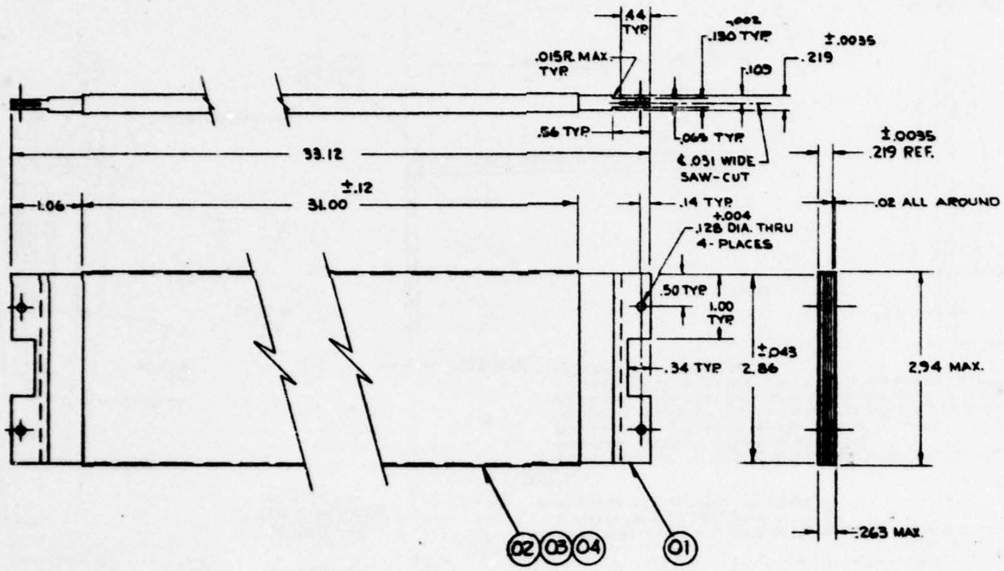
GENERAL NOTE:

1- INSULATION SYSTEM MUST BE SUITABLE FOR CO_2 SATURATED WITH WATER VAPOR AT 80°F DEW POINT. ENVIROMENT AT A PRESSURE OF 5 P.S.I. INSULATION SYSTEM MAY BE AS SPECIFIED OR AN EQUIVALENT SYSTEM MAY BE PROPOSED THAT IS RESISTANT TO HYDROLYSIS. STATOR BAR RATING - 500 VOLTS.

TITLE 3,000 H.P., 6-POLE MOTOR RETURN CONDUCTOR - STATOR

DWG 2615C10 REV 1

ITEM	NOTE	PART NAME	DSP	USED REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		STATOR BAR	DWG		1693B52		1				
02		KAPTON TAPE			PDS447898A		AS REQD				
03		GLASS TAPE		.005 THK	PDS41514CL		AS REQD				
04		RESIN			M5384IFD		AS REQD				



Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR RETURN CONDUCTOR - STATOR

REV 1

SCALE 1:1

T. GRADISEK

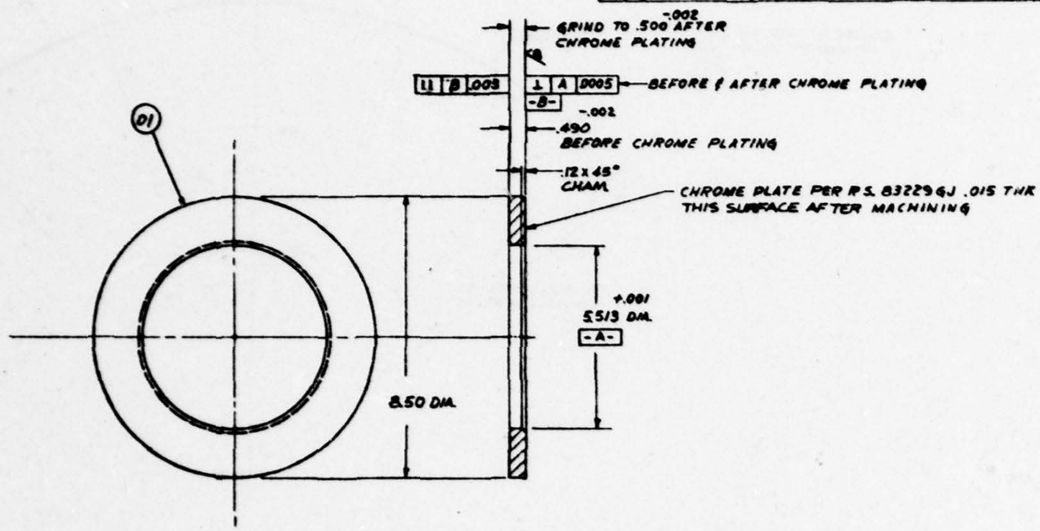
REF DWG 659F495

2615C10

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH, PA. 15235 U.S.A.

TITLE 3,000 H.P. 6 POLE MOTOR
THRUST COLLAR - ROTOR BEARING
DWG 2615C16 REV

ITEM	NOTE	PART NAME	REF	USED REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER R&D STK NR	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		THRUST COLLAR		9.00 x 9.00 OF .625 THK SST PL TYPE 304	7803-0101		1				



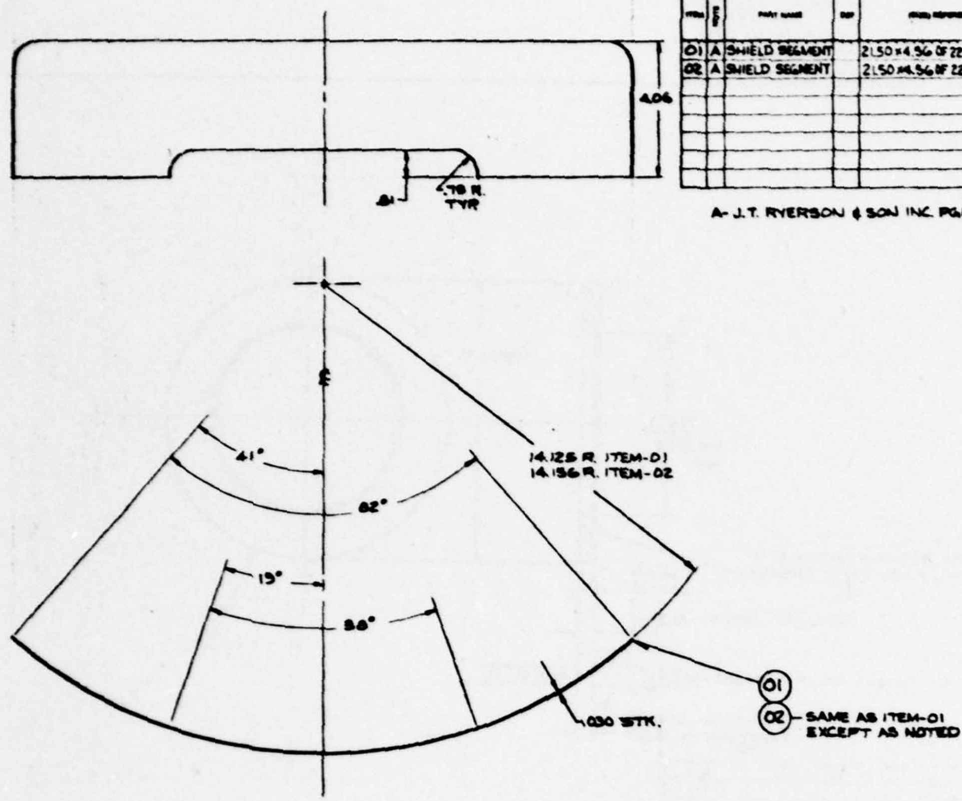
Westinghouse Electric Corporation
TITLE 3,000 H.P. 6 POLE MOTOR
THRUST COLLAR - ROTOR BEARING
SCALE 1:2
REV. 1
1289J56
2615C16
RESEARCH LABORATORIES ... PITTSBURGH, PA. U.S.A.
CHANGE

TITLE 3,000 H.P., 6-POLE MOTOR
FLUX SHIELD SEGMENTS - FIELD COIL - STATOR

DWG 2615C19 REV. 1

ITEM	NOTE	PART NAME	DEP	MATL REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01	A	SHIELD SEGMENT		21.50 × 4.56 OF 22 GA. (.0299 THK.) H.R.S. SH.		ASTM A-415	1				
02	A	SHIELD SEGMENT		21.50 × 4.56 OF 22 GA. (.0299 THK.) H.R.S. SH.		ASTM A-415	1				

A- J.T. RYERSON & SON INC. PGH., PA.



Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
FLUX SHIELD SEGMENTS - FIELD COIL - STATOR

SCALE 1:2 REV. 1

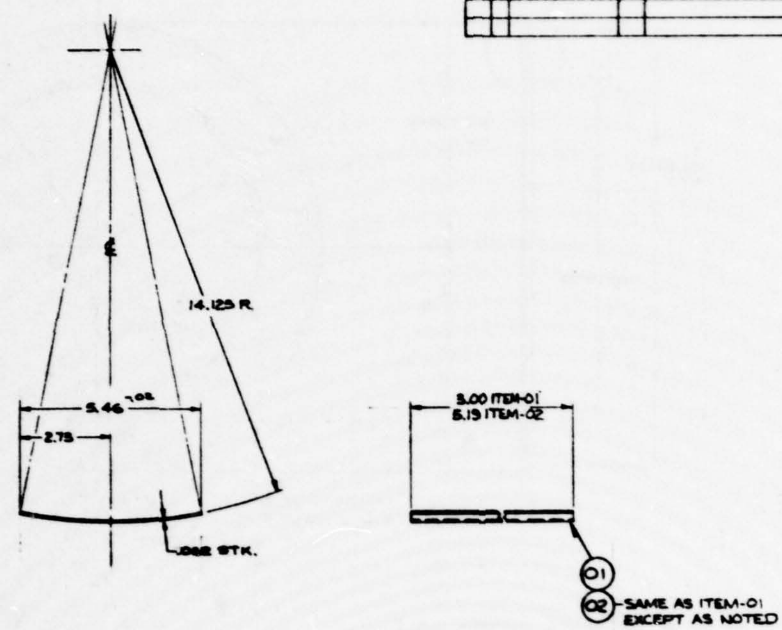
J. SABINO

2615C19

6822D08

TITLE 3,000 H.P., 6-POLE MOTOR
SUPPORT - FIELD COIL
DWG 2615C20 REV. 1

ITEM	NOTE	PART NAME	REF	REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STOCK NO.	PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01		COIL SUPPORT		3.50 x 6.80 OF 16 GA. (.062 THK.) SST. SH.	9306-0101	TYPE 304	1				
02		COIL SUPPORT		5.75 x 6.80 OF 16 GA. (.062 THK.) SST. SH.	9306-0101	TYPE 304	1				

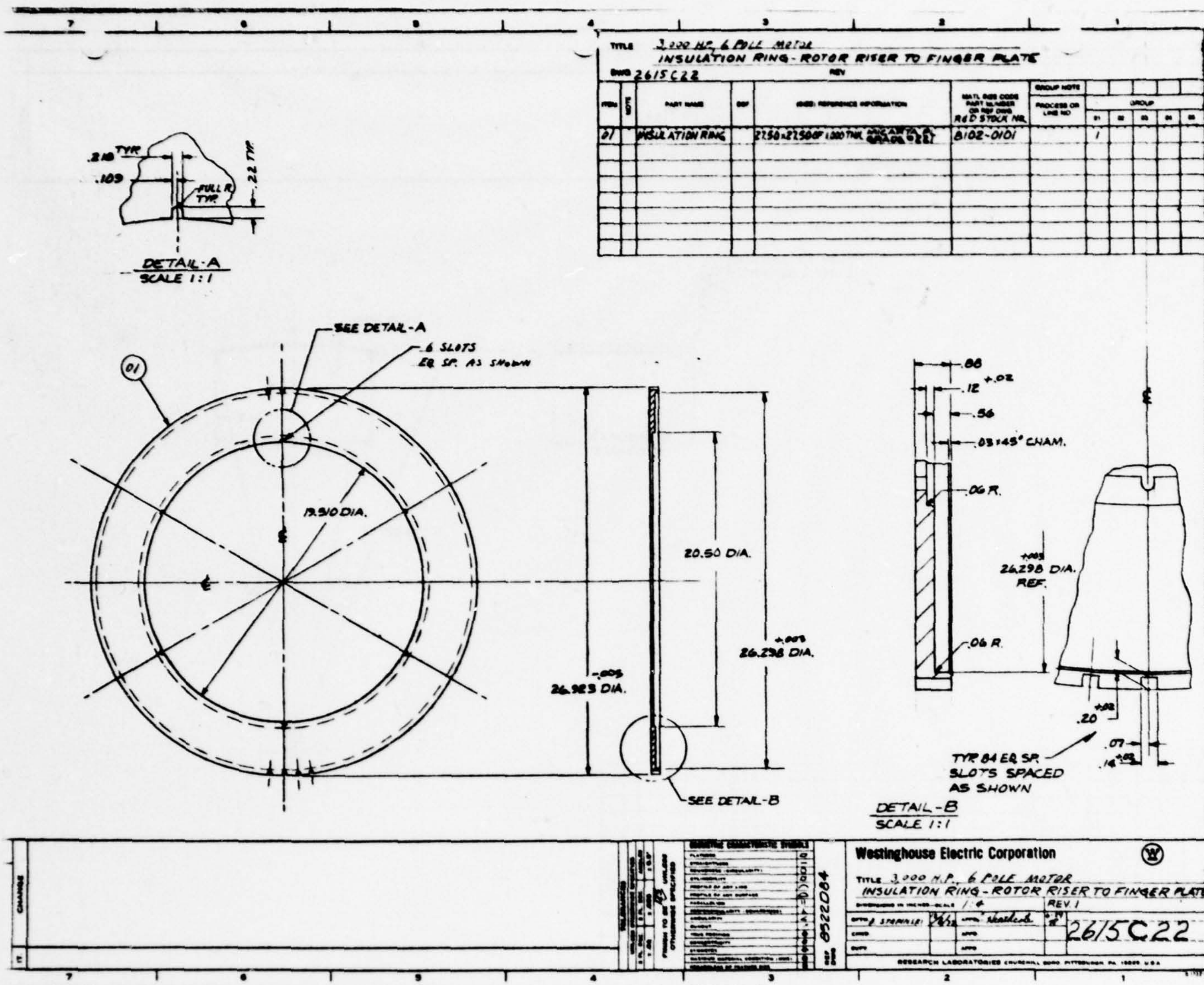


8522D05
1289J54

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
SUPPORT - FIELD COIL
SCALE 1:2
REV. 1
DRAWN J. Eastman
2615C20

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA. U.S.A.



TITLE 3,000 HP, 6 POLE MOTOR
INSULATION RING - ROTOR RISER TO FINGER PLATE
DWG 2615C22
01
INSULATION RING
B102-0101
DETAIL-A
SCALE 1:1
.218 TYP.
.109
FULL R. TYP.
.22 TYP.
SEE DETAIL-A
6 SLOTS EQ. SP. AS SHOWN
19.910 DIA.
20.50 DIA.
26.298 DIA.
26.923 DIA.
SEE DETAIL-B
.88
.12
.56
.03×45° CHAM.
.06 R.
.06 R.
26.298 DIA. REF.
.20
.07
.14
TYP. 84 EQ. SP. SLOTS SPACED AS SHOWN
DETAIL-B
SCALE 1:1
Westinghouse Electric Corporation
TITLE 3,000 H.P. 6 POLE MOTOR
INSULATION RING - ROTOR RISER TO FINGER PLATE
REV 1
1:4
8522D84
2615C22
CHANGE

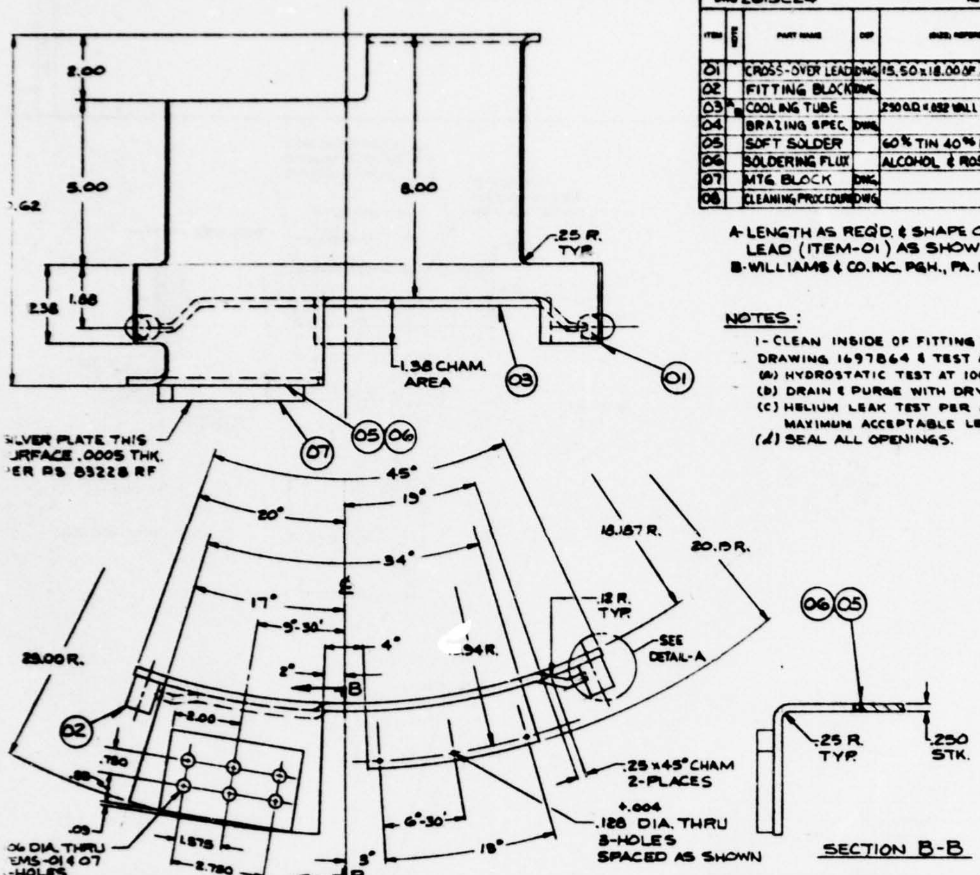
TITLE 3,000 H.P. 6-POLE MOTOR
CROSS CONNECTOR-STATOR RETURN CONDUCTOR
DWG 2615C24 REV 1

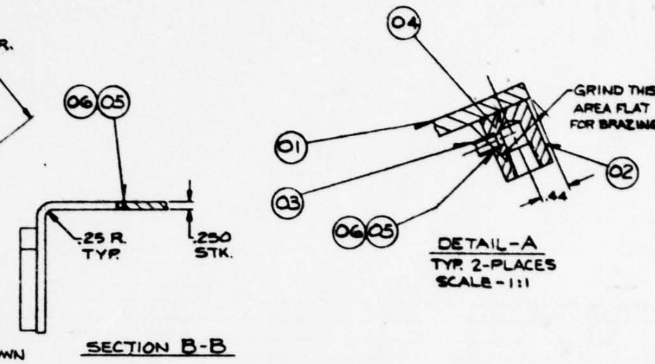
ITEM	NOTE	PART NAME	DSP	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		CROSS-OVER LEAD	DWG	15.50 x 18.00 OF .250 THK. CU.	1693B52		1				
02		FITTING BLOCK	DWG		1692B69H01		2				
03	A B	COOLING TUBE		.250 O.D. x .032 WALL SOFT CU. TUBING ½ HARD		ASTM B-75	1				
04		BRAZING SPEC.	DWG		6439A64		AS REQ'D				
05		SOFT SOLDER		60% TIN 40% LEAD	PDS17630AG		AS REQ'D				
06		SOLDERING FLUX		ALCOHOL & ROSIN	M53501AA		AS REQ'D				
07		MTG. BLOCK	DWG		1696B82H01		1				
08		CLEANING PROCEDURE	DWG		1697B64		REF				

A-LENGTH AS REQ'D & SHAPE OF TUBING TO FOLLOW CONTOUR OF CROSS-OVER LEAD (ITEM-01) AS SHOWN
B-WILLIAMS & CO. INC. PGH., PA. 15233.

NOTES:

1- CLEAN INSIDE OF FITTING BLOCKS (ITEM-02) & COOLING TUBE (ITEM-03) PER DRAWING 1697B64 & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 P.S.I. FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST PER ASTM E-499 METHOD "A" AT 10 P.S.I.G. MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD $1 \times 10^{-6}\ \frac{CM^3}{S}$
(d) SEAL ALL OPENINGS.

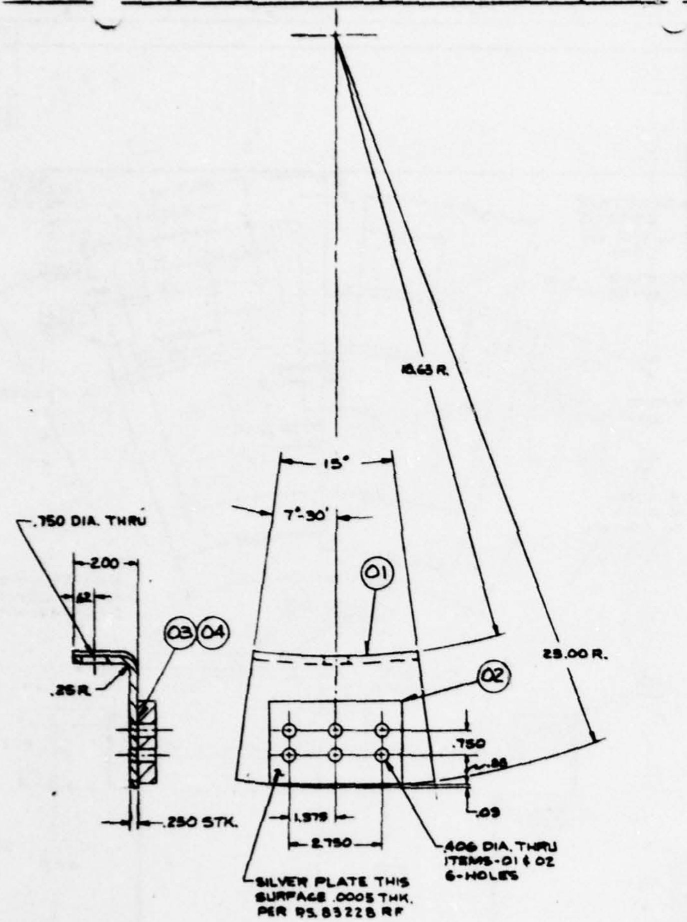




Westinghouse Electric Corporation
TITLE 3,000 H.P. 6-POLE MOTOR
CROSS CONNECTOR-STATOR RETURN CONDUCTOR
SCALE 1:2
REV. 1
DFTR. J. SABINO
2615C24
1289J54
RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA. 15235 U.S.A.

TITLE 3,000 H.P., 6-POLE MOTOR
CONNECTOR - END CONNECTOR TO BRUSH SHUNT
DWG 2615C27 REV. 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		END CONNECTOR	DWG.	7.25 × 6.50 OF .750 THK. CU.	1695B52		1				
02		MTG. BLOCK	DWG.		1696B82H01		1				
03		SOFT SOLDER		60% TIN 40% LEAD	P0517630AG		AS REQ'D.				
04		SOLDERING FLUX		ALCOHOL & ROSIN	M53301AA		AS REQ'D.				



CHANGES

UNLESS OTHERWISE SPECIFIED

REF DWG 1289J54

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
CONNECTOR - END CONNECTOR TO BRUSH SHUNT

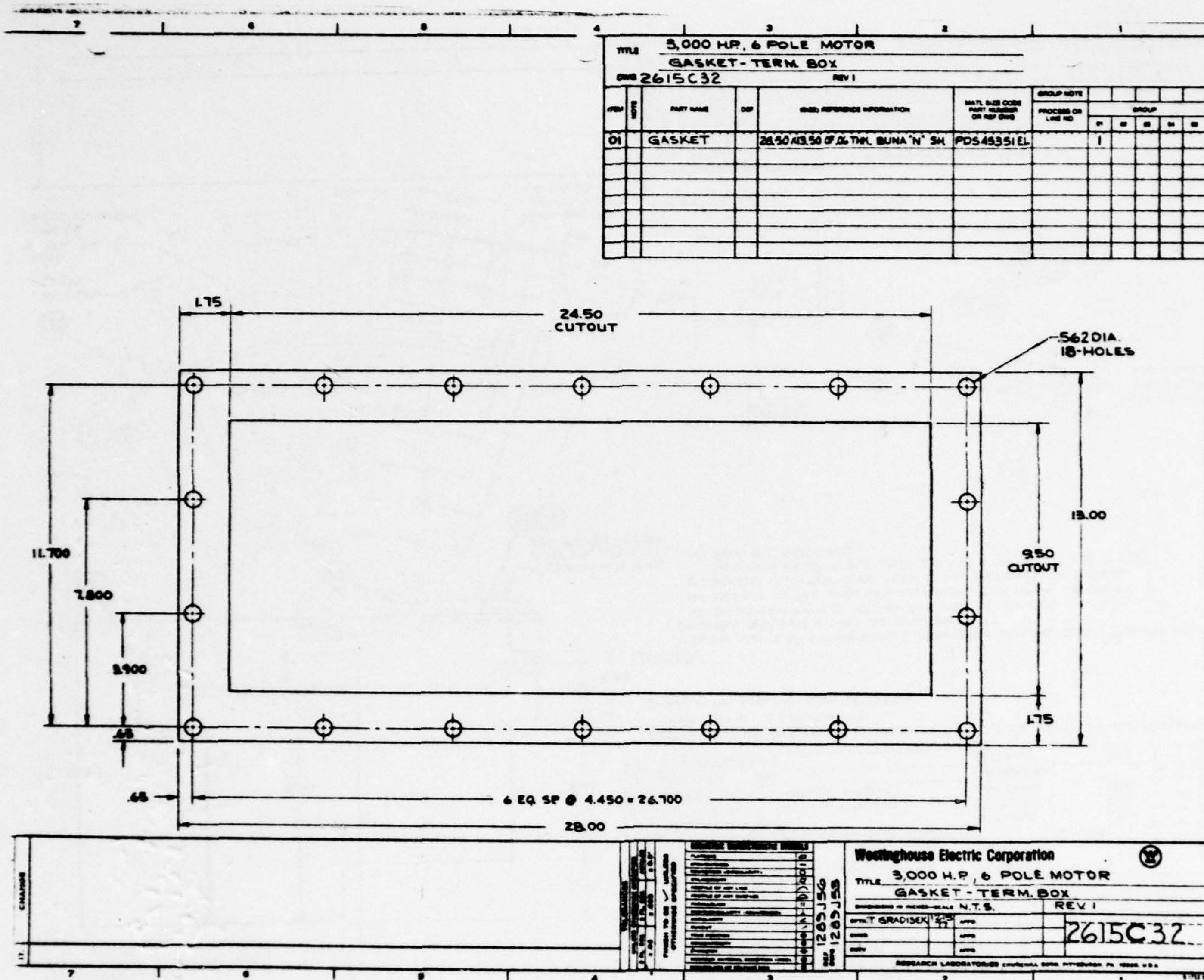
DIMENSIONS IN INCHES - SCALE 1:2

REV. 1

DFTR J. SABINO

2615C27

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH, PA. 15235 U.S.A.



TITLE 3,000 H.P. 6 POLE MOTOR
GASKET - TERM. BOX
DWG 2615C32
REV I
01 GASKET 28.50 X 13.50 OF .06 THK. BUNA "N" SH PDS45351EL 1
24.50
CUTOUT
1.75
.562 DIA.
18-HOLES
13.00
9.50
CUTOUT
11.700
7.800
3.900
.65
6 EQ. SP @ 4.450 = 26.700
28.00
Westinghouse Electric Corporation
3,000 H.P. 6 POLE MOTOR
GASKET - TERM. BOX
N.T.S.
T GRADISEK
2615C32
1285J56
1285J58

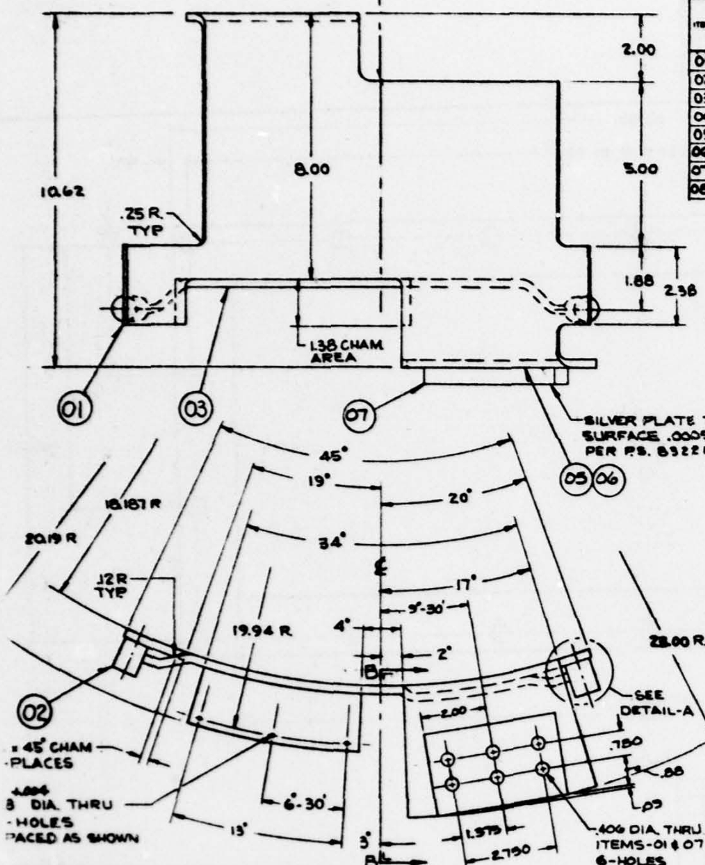
TITLE 3,000 H.P., 6-POLE MOTOR
CROSS CONNECTOR-STATOR RETURN CONDUCTOR
DWG 2615C36 REV 1

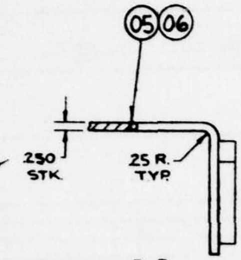
ITEM	NOTE	PART NAME	DEP	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP
01		CROSS-OVER LEAD	DWG	15.50×18.00 OF .250 THK. CU.	1693B52		1
02		FITTING BLOCK	DWG		1692B69H01		2
03	A	COOLING TUBE		.250 O.D. ×.032 WALL SOFT CU TUBING ¼ HARD		ASTM B-75	1
04		BRAZING SPEC.	DWG		6439A64		AS REQ'D
05		SOFT SOLDER		60% TIN 40% LEAD	PDS11630AG		AS REQ'D
06		SOLDERING FLUX		ALCOHOL & ROSIN	M53301AA		AS REQ'D
07		MTG. BLOCK	DWG		1696B82H01		1
08		CLEANING PROCEDURE	DWG		1697B64		REF

A-LENGTH AS REQ'D & SHAPE OF TUBING TO FOLLOW CONTOUR OF CROSS-OVER LEAD (ITEM-01) AS SHOWN.
B-WILLIAMS & CO. INC. PGH., PA. 15233.

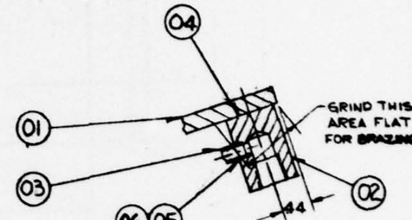
NOTES:

1-CLEAN INSIDE OF FITTING BLOCKS (ITEM-02) & COOLING TUBE (ITEM-03) PER DRAWING 1697B64 & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 P.S.I. FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST PER ASTM E-499 METHOD "A" AT 10 P.S.I.G. MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD $1 \times 10^{-6}\ \frac{CM^3}{S}$
(d) SEAL ALL OPENINGS.





SECTION B-B



DETAIL-A
TYP. 2-PLACES
SCALE-1:1

REF DWG 1289J54

Westinghouse Electric Corporation
TITLE 3,000 H.P., 6-POLE MOTOR
CROSS CONNECTOR-STATOR RETURN CONDUCTOR
SCALE 1:2 REV 1
DFTR T. GRADISEK
2615C36
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

TITLE 3000 H.P., 6 POLE MOTOR ROTOR STACKING PROCEDURE

DWG 2615C75 REV

ITEM	NOTE	PART NAME	DEP	(REF) REFERENCE INFORMATION	MAT'L DIES CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05

Rotor Stacking Procedure

1. With the shaft in a vertical position, assemble one end plate, one split retainer and six retainer roll pins on the lower end.

2. Install key in keyway and rest shaft on the base plate of a suitable press of at least 25 tons capacity.

3. Place the entire core length of punchings in an oven and heat to 385 ± 25°F
   (a) All punchings must be those assigned to the individual shaft.
   (b) Punching burrs must face the same direction.
   (c) Punchings must be stacked in the same sequence as punched.

4. Using a contact pyrometer, verify that punchings are at 385 ± 25°F and assemble a 5" stack in increments of approx. .50" to .75" onto the rotor shaft using the key to provide alignment.

5. Using an equalizer press ring, press punchings to 25 tons and hold for approx. 1 minute. Repeat this load and unload cycle 3 times.

6. Load to 25 tons and hold while using forced air cooling on the punchings and until their temperature reaches 110°F.

7. Reduce press load to zero and examine stack. If top punchings are convex (area around the shaft higher than area at O.D.) and/or loose, have inspector reject.

8. If stack is acceptable, assemble balance of punchings in 5" increments per sequence 3 to 6 until the (motor 31.2") punching length is attained.

9. Install the top end plate and press to 25 tons, hold and verify that the end plate extends beyond the circumferential groove for the split retainer as shown in detail C Dwg. 8521D43. Add or subtract punchings until extension is achieved.

10. Clamp the entire assembly axially so that when the press load is released, the 25 tons punching load is maintained and the clamping device leaves accessability to the end plate in the region discussed in step 9.

11. After clamping, release the press load and machine the end plate per detail C. Dwg. 8521D43.

12. Install split retainer and six roll pins then remove clamp.

13. Inspect stack for tightness.

8521D43

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR ROTOR STACKING PROCEDURE

REV. 1

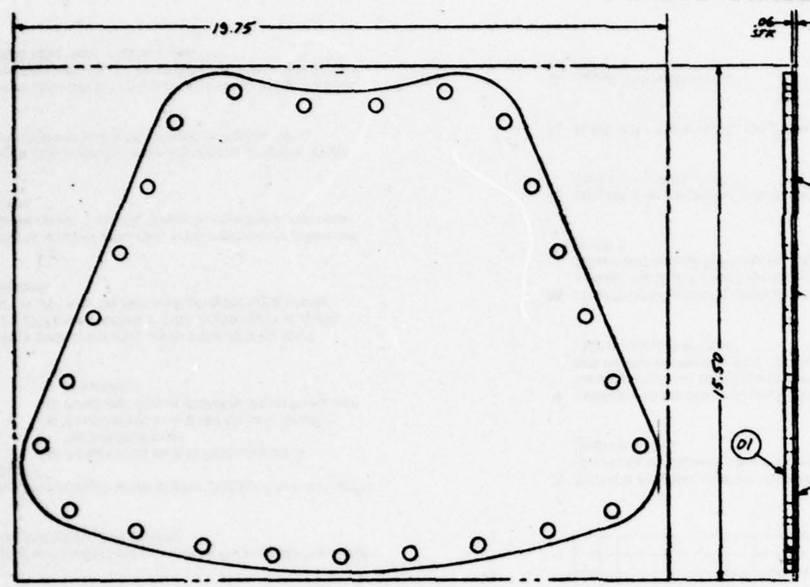
2615C75

RESEARCH LABORATORIES

TITLE 3,000 H.P., 6 POLE MOTOR
BRUSH ACCESS COVER GASKET
DWG 2615CB2 REV. 1.

ITEM	NOTE	PART NAME	DSF	REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STOCK NO.	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	COVER PLATE			8521D85 H01		REF				
02		GASKET		19.75 x 15.50 OF .06 THK. BUNA "N" SH.	PDS4535 1EL		1				

A-ITEM-01 TO BE USED AS A TEMPLATE FOR MAKING ITEM-02.



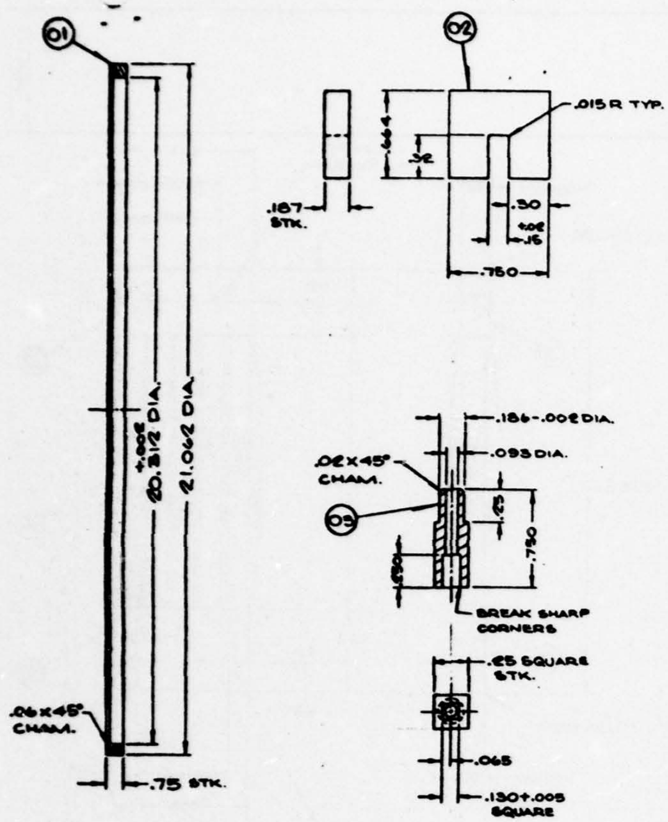
NOTES:
1: USE IT. 01 AS A TEMPLATE AND CUT ITEM. TO SAME SIZE & SHAPE.

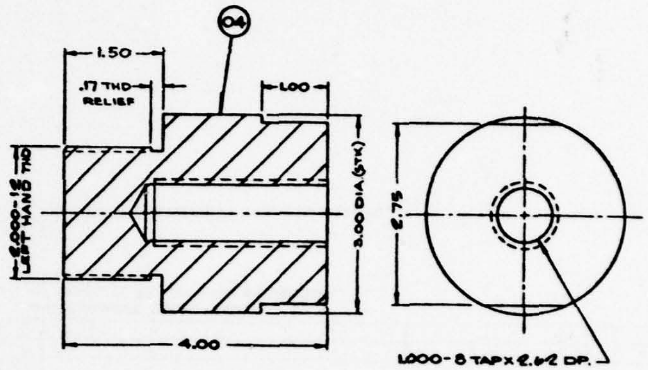
Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR
BRUSH ACCESS COVER GASKET
SCALE 1:2
REV. 1
DFTR A. STAPINSKI
REF DWG 8521D85, 1283J56
2615CB2
RESEARCH LABORATORIES, CHURCHILL BORO, PITTSBURGH, PA. 15235 U.S.A.

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - INSUL RING, BAL BLOCK, ADAPTER & FIXTURE DETS
DWG 2616C61 REV 1

ITEM	NOTE	PART NAME	QTY	REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STK NO	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04
01		INSUL RING		21.25 X 21.25 OF .75 THK MICARTA	8702-0101	GR 221				
02		BALANCE BLOCK		.88 OF .187 X .750 BRASS BAR	6009-0901	ASTM B-16				
03		ADAPTER		1.00 OF .250 DIA BRASS BAR	5905-1101	ASTM B-16				
04		ROTOR FIXTURE		4.12 OF 3.00 DIA CR STL ROD	5902-0101	AISI B1113				





Westinghouse Electric Corporation

TITLE 3000 HP, 4 POLE GENERATOR
ROTOR - INSUL RING, BAL BLOCK, ADAPTER & FIXTURE DETS
NTS REV 1
2616C61

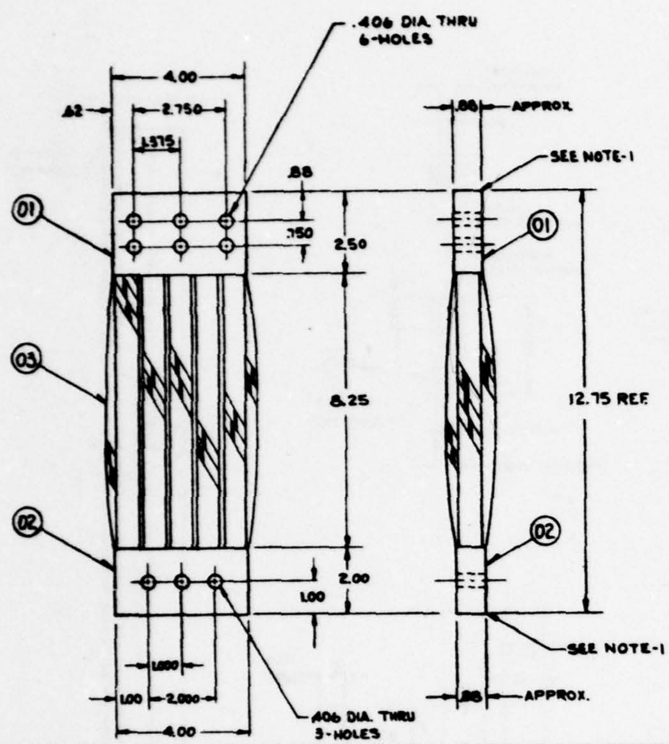
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.

TITLE 3,000 H.P. 6-POLE MOTOR
SHUNT DETAIL - BRUSH HOLDER
DWG 2616C62 REV 1

ITEM	NOTE	PART NAME	QTY	REFERENCE INFORMATION	MAT'L CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	B	FERRULE					1				
02	B	FERRULE					1				
03	A	CABLE		1 X 7 X 106/34 [illegible]/34 EXTRA FLEX. ROPE LAY-TINNED			15				

A - TELEDYNE PENN-UNION.
B - MAT'L TO BE SUPPLIED BY VENDOR.

NOTE:
1 - SILVER PLATE .0002 THK. ALL AROUND.

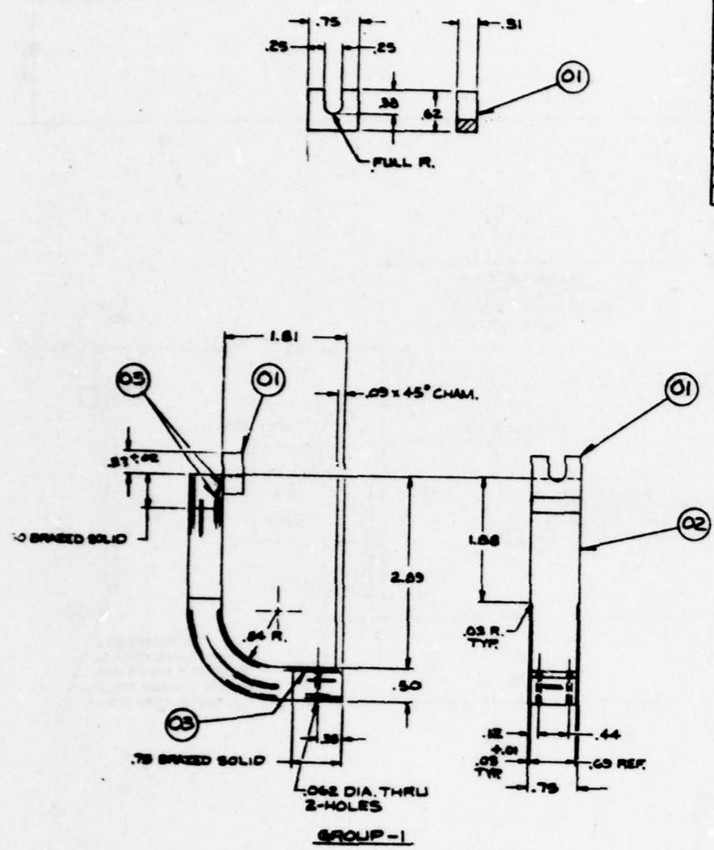


Westinghouse Electric Corporation
TITLE 3,000 H.P. 6-POLE MOTOR
SHUNT DETAIL - BRUSH HOLDER
REV. 1
SCALE 1:2
T. GRADISEK
DWG 2616C62
REF DWG 1289J56
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA.

TITLE 3,000 H.P. 6-POLE MOTOR RISER-ROTOR

DWG 2616C70 REV. 1

ITEM	NOTE	PART NAME	REF	SIZE, REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	GROUP 01
01		TAB		1.00 X .88 OF .375 THK. SILVER CU.	PDS2007		1
02		LAMINATION		.020 THK. SILVER CU. SH.	PDS2007		AS REQD
03		BRAZING SPEC.	DWG		6439A67		AS REQD



Westinghouse Electric Corporation

TITLE 3,000 H.P. 6-POLE MOTOR RISER-ROTOR

SCALE 1:1

REV. 1

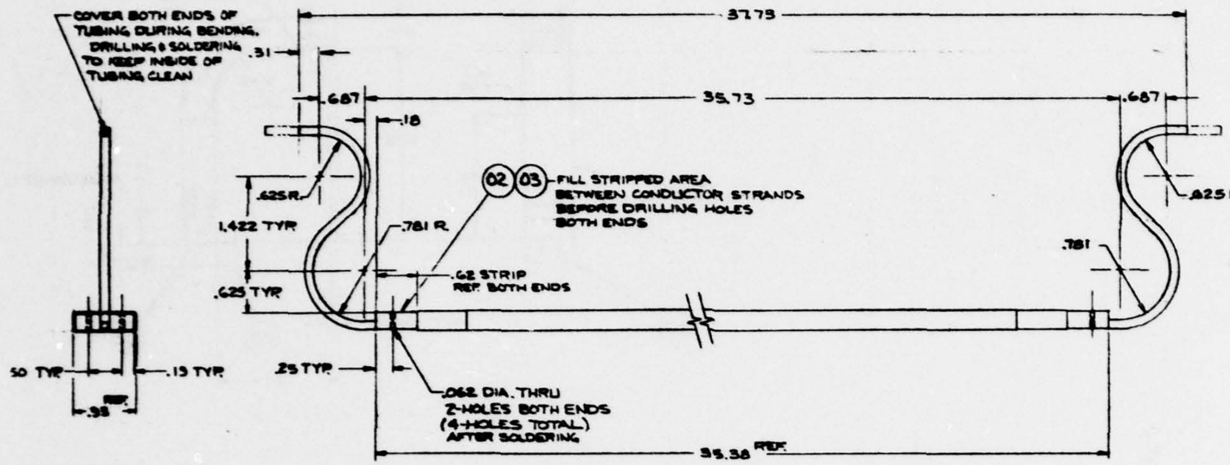
DFTR J. SABINO

2616C70

8522D83

TITLE 3,000 H.P., 6-POLE MOTOR
CONDUCTOR DETAIL-ROTOR
DWG 2616C71 REV. 1

ITEM	NOTE	PART NAME	DEF	(RSO) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP P1	02	03	04	05
01		CONDUCTOR	DWG		6427A71H01		1				
02		SOFT SOLDER		60% TIN 40% LEAD	P0517630AG		AS REQD				
03		SOLDERING FLUX		ALCOHOL & ROSIN	M53301AA		AS REQD				



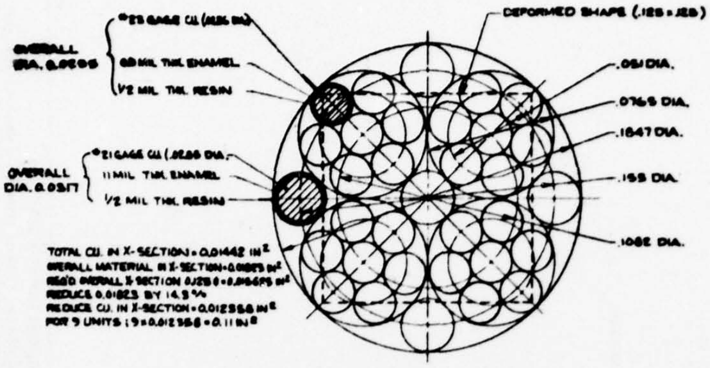
CHANGE

REF DWG 8522D89

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
CONDUCTOR DETAIL-ROTOR
DIMENSIONS IN INCHES-SCALE 1:1 REV. 1
DFTR J. SABINO
2616C71

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA. 15235 U.S.A.



SUBCABLE PREPARATION

STEP 1. Cut the subcable to appropriate lengths, about 5 feet, and set the epoxy. The square subcable is unreeled from the shipping reel, cut to lengths, and placed in a 270°F furnace to soften the epoxy. After a few minutes, the cable is removed from the furnace and placed between flat plates for cooling. Upon removal from the flat plate, the cable is a rigid, straight unit, assuming that the subsequent bending operation can be effectively performed.

STEP 2. Produce 30°-angles. This is the most severe of the forming operations to which the square subcable is subjected and, therefore, requires particular precautions to prevent the formation of strand-to-strand shorts. The rate of wire movement during bending should be relatively slow, while force motion perpendicular to the bending plane must be assured. As a result, some spreading at the bend occurs which is corrected in the next operation.

STEP 3. Compress bend areas perpendicular to the plane of bend to a size 2-4 mils smaller than undeformed dimensions. For example, if the square wire is 0.125 × 0.125 inch at the start, its dimension perpendicular to the plane of bending is going to be set at 0.122 inch. No provisions should be made to restrict cable movement in the plane of bend during this compression operation. This undersizing is necessitated by the very tight tolerances of the assembled cable. During the assembly generation, a 2 mil thick insulation is placed between the "roebel" bend and adjacent subcable to prevent subcable-to-subcable shorts from developing. In order to accommodate this insulation, undersizing of the subcable is necessary.

STEP 4. Separate and strip ends from insulation in a preparation for testing for strand-to-strand shorts. Approximately 2 inch lengths at each end of the subcable are spread by a pair of pliers. One of the spread ends is subsequently immersed in a solution of hot (750°F) stripping solution for a period of about 30 seconds. Upon removal, the stripped end is thoroughly rinsed in running water.

STEP 5. Test subconductor for strand-to-strand shorts. The test is carried out by sequentially shorting strand-ends through an ohm-meter. Having tested the first two strands, they are permanently shorted to each other (twisted together to form a connection) and the next strand is tested against this connection. A total of 32 measurements are required for fully testing a subconductor.

STEP 6. Cut to length. Subconductors are cut to finished length. This operation removes the spreaded ends. It is important that a clean, "square" cut be made, since in the final assembling operation the ends must fit together to form a close packed rectangle.

STEP 7. Strip ends for finished joints. One-half inch of insulation is stripped away from each end. This step is similar to Step 6 except that no spreading is involved. Following the stripping process, the ends are thoroughly rinsed in running water to remove residues of the stripping agent. The end cleanliness is further improved by the application of a 3-5% nitric acid dip which is followed by repeated rinsing.

STEP 8. Produce all other bends required. All small angle bends are made in this operation.

ASSEMBLING AND SETTING

Starting materials: A pair of subconductors for each position of the conductor bar prepared as per description of the previous section; also a pre-bent cooling tube.

STEP 1. Assemble halves of the conductor bar. In one of the halves the cooling tube occupies the center position. A simple alignment of the ends of each set assures the proper relative positioning of the Roebel bends (30° bends). In order to preserve this alignment during further handling, the ends of the half bars are secured by Teflon tape.

STEP 2. Assemble two halves, apply room temperature (R.T.) curing resin to the interfaces and mylar insulation to the Roebel bends. R.T. resin is brushed lightly on the interfaces of the halves in the vicinity of the Roebel bends. The two halves are joined and the alignment is secured by taping (Teflon) the ends together. Previous taping is removed at this time. Pre-cut pieces of Roebel insulators are carefully inserted. The insulator must extend beyond the actual Roebel bend by approximately 0.5-0.75 inch.

STEP 3. Press to size and test for subcable-to-subcable shorts. Prior to placing the subcables into a sizing mold, R.T. resin is brushed lightly on the outside surfaces in the vicinity of the Roebel bends. Tapes are also removed from the ends and the conductor bar is positioned in a mold. The mold is subsequently closed and tightened to predetermined dimensions. This step assures that the conductor bar meets the stringent tolerance ± .003" requirements. For testing purposes, the stripped ends are separated from each other by sheets (2 mils thick) of mylar insulator. An ohm-meter is then used to test the assembly for subcable-to-subcable shorts. Having completed the test, the end insulator sheets are removed and the conductor bar is left in the mold for a period of approximately 8 hours to permit the R.T. resin to fully cure. After curing, the conductor bar is ready for further insulation.

STEP 4. Apply insulation. A 10 mil strip of glass tape is laid along the wide side of the conductor, on the side opposite from the cooling tube on the ends. The loaded mica tape is then wrapped on, one layer, half lapped.

STEP 5. Final cure. The insulated bar is placed in a mold to fix the final dimensions. This assembly is then put in a 300°F furnace to cure for 1.5 hours at temperature. After cool down, the finished conductor bar is removed from the mold.

Westinghouse Electric Corporation

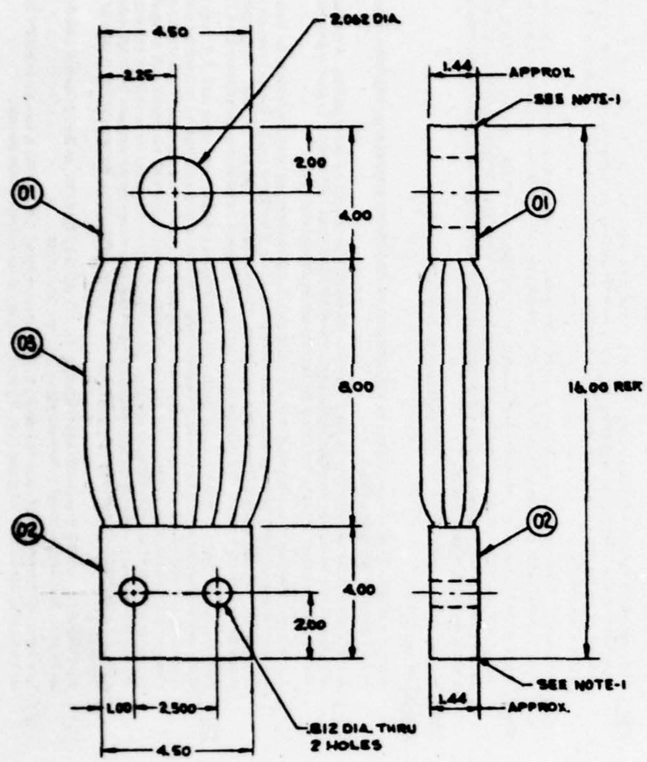
TITLE 3,000 H.P. 6-POLE MOTOR CONDUCTOR BAR MANUFACTURING SEQUENCE

REV. 1

2616C74

6427A71

57



TITLE 3,000 H.P., 6-POLE MOTOR & 4 POLE GENERATOR
SHUNT DETAIL - TERMINAL BOX
DWG 2618C13 REV #2

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO	01	02	03	04	05
01	B	FERRULE					1				
02	B	FERRULE					1				
03	A	CABLE		5400 MCM BRAID			12				

A - TELEDYNE PENN-UNION.
B - MAT'L TO BE SUPPLIED BY VENDOR.

NOTE:
1 - SILVER PLATE .0002 THK ALL AROUND.

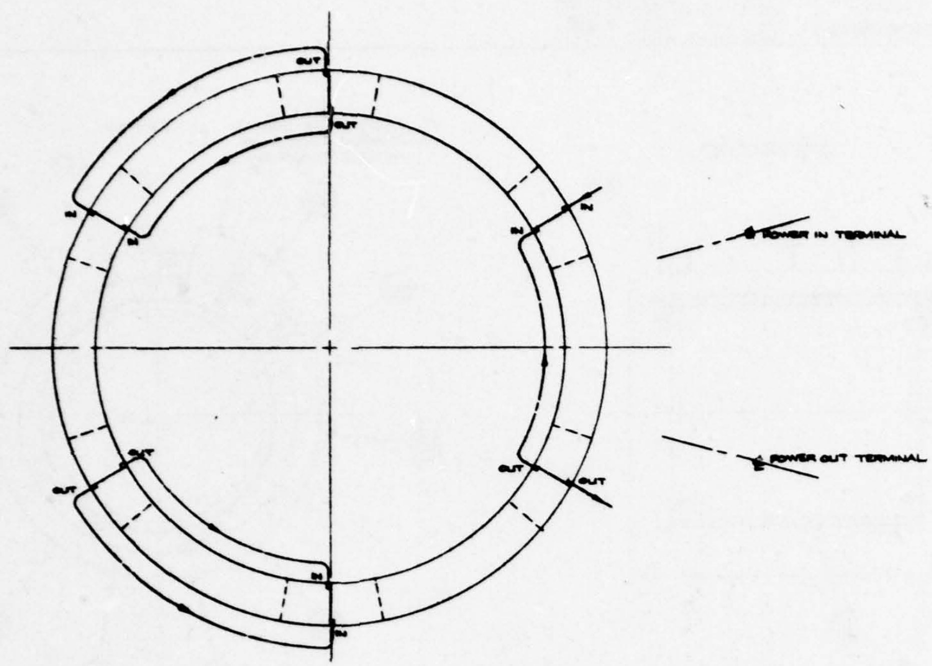
CHANGE	
REVISED	2
TPG 7-14-78	

REF DWG 1289J56

Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR & 4 POLE GENERATOR
SHUNT DETAIL TERMINAL BOX
DIMENSIONS IN INCHES - SCALE 1:2
REV. #2
DRFTR T.GRADISEK
2618C13

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA 15235 U.S.A.



Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR
WIRING PROCEDURE-FIELD COILS

N.T.S. REV. 1

J. SABINO

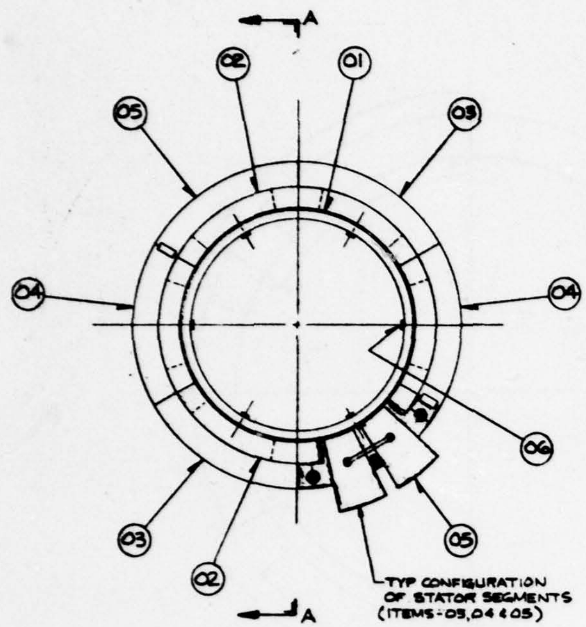
2618C28

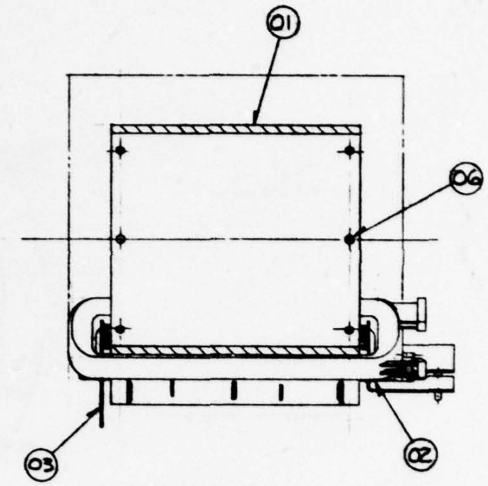
1289J54

CHANGE

TITLE 3,000 H.P. 6-POLE MOTOR
STATOR ASSEMBLY PROCEDURE
DWG 2618C29 REV. 1

ITEM	NOTE	PART NAME	DFT	AREA REFERENCE INFORMATION	MAT'L SPEC CODE PART NUMBER OR REF DWG	PROCESS OR LINE NO.	QTY
01		MANDREL					REF
02		FIELD COIL	DWG.		8521D12G01		6
03		STATOR SEGMENT	DWG.		693F493G01		2
04		STATOR SEGMENT	DWG.		693F493G02		2
05		STATOR SEGMENT	DWG.		693F493G03		2
06		BOLT		.500-13 HEX HD. STL.			12





SECTION A-A

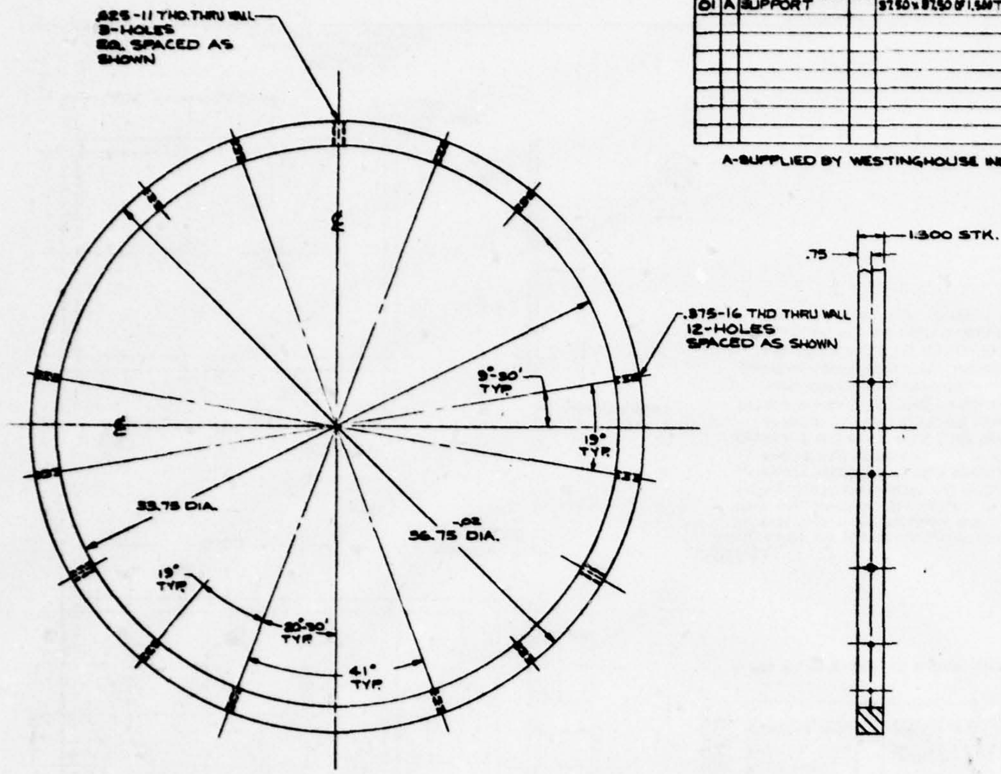
Westinghouse Electric Corporation

TITLE 3,000 H.P. 6-POLE MOTOR
STATOR ASSEMBLY PROCEDURE
SCALE 1:8 REV 1
DFTR J. SABINO
REF DWG 1289J54
2618C29
RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA.

TITLE 5,000 H.P., 6-POLE MOTOR
SUPPORT-END CONNECTOR
DWG 2618C44 REV. 1

ITEM	NOTE	PART NAME	DSP	(ASSD) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE / PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	SUPPORT		37.50 x 37.50 OF 1.500 THK MICARTA PL. [illegible]			1				

A-SUPPLIED BY WESTINGHOUSE INDUSTRIAL PLASTICS DIV. HAMPTON, S. CAROLINA



Westinghouse Electric Corporation

TITLE 5,000 H.P., 6-POLE MOTOR
SUPPORT-END CONNECTOR

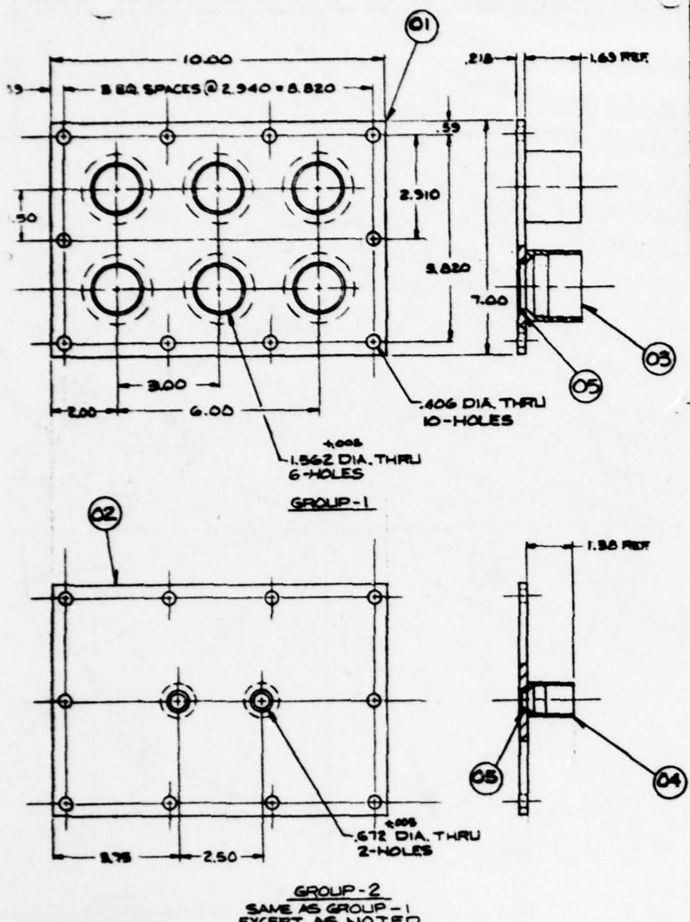
DIMENSIONS IN INCHES—SCALE 1:4 REV. 1

DFTR J. SABINO — APPD [illegible]

2618C44

REF DWG 1289J54

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH, PA. 15235 U.S.A.



TITLE 3,000 H.P. 6-POLE MOTOR & 4-POLE GEN.
STUFFING TUBE MTG. PLATES-TERM. BOX
DWG 2618C72 REV. 1

ITEM	NOTE	PART NAME	QTY	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG R&D STOCK NO.	PROCESS OR LINE NO.	GROUP 01	02	03	04	05
01		MTG. PLATE		10.50×7.50 OF .250 THK. H.R.S. PL.	8205-0101		1	-			
02		MTG. PLATE		10.50×7.50 OF .250 THK. H.R.S. PL.	8205-0101		-	1			
03	A	STUFFING TUBE BODY		PART NR M24235/14-041			6	-			
04	A	STUFFING TUBE BODY		PART NR M24235/14-032			-	2			
05		FLUX PASTE			M53303AA		AS REQ'D	AS REQ'D			
06		BRAZING RING		.062 DIA. × 4.88 LG.	PDS16370CF		6	-			
07		BRAZING RING		.062 DIA. × 2.06 LG.	PDS16370CF		-	2			

A-PER MIL-S-24235/14 SHIPS (MACHINED BRASS).

NOTES:

1-METHOD OF BRAZING STUFFING TUBES:
AFTER THE PLATES HAVE BEEN DRILLED FOR THE STUFFING TUBE SIZE USED, THE FOLLOWING PROCEDURE IS RECOMMENDED FOR THE SILVER BRAZING OPERATION.
(a) ALL SURFACES MUST BE FREE FROM OIL, GREASE & SCALE PRIOR TO HEATING.
(b) PAINT NECK OF TUBE & AREA AROUND HOLE IN PLATE WITH FLUX PASTE M53303AA.
(c) PLACE BRAZING RING (.062 DIA CROSS SECTION) OVER NECK OF TUBE & INSERT IN HOLE IN PLATE. SILVER ALLOY WIRE TO BE PER PDS 16730CF.
(d) THE WEIGHT OF THE TUBE GIVES SUFFICIENT PRESSURE ON A HORIZONTAL SURFACE.
(e) HEAT UNIFORMLY BY MEANS OF OXYACETYLENE TORCH UNTIL RING MELTS & FILLETS AROUND THE TUBE & PLATE.
(f) FLUX MUST BE REMOVED BY APPLICATION OF WATER OR A WET RAG TO THE HOT TUBE & PLATE.

CHANGE

REF DWG 1289J56
1289J53

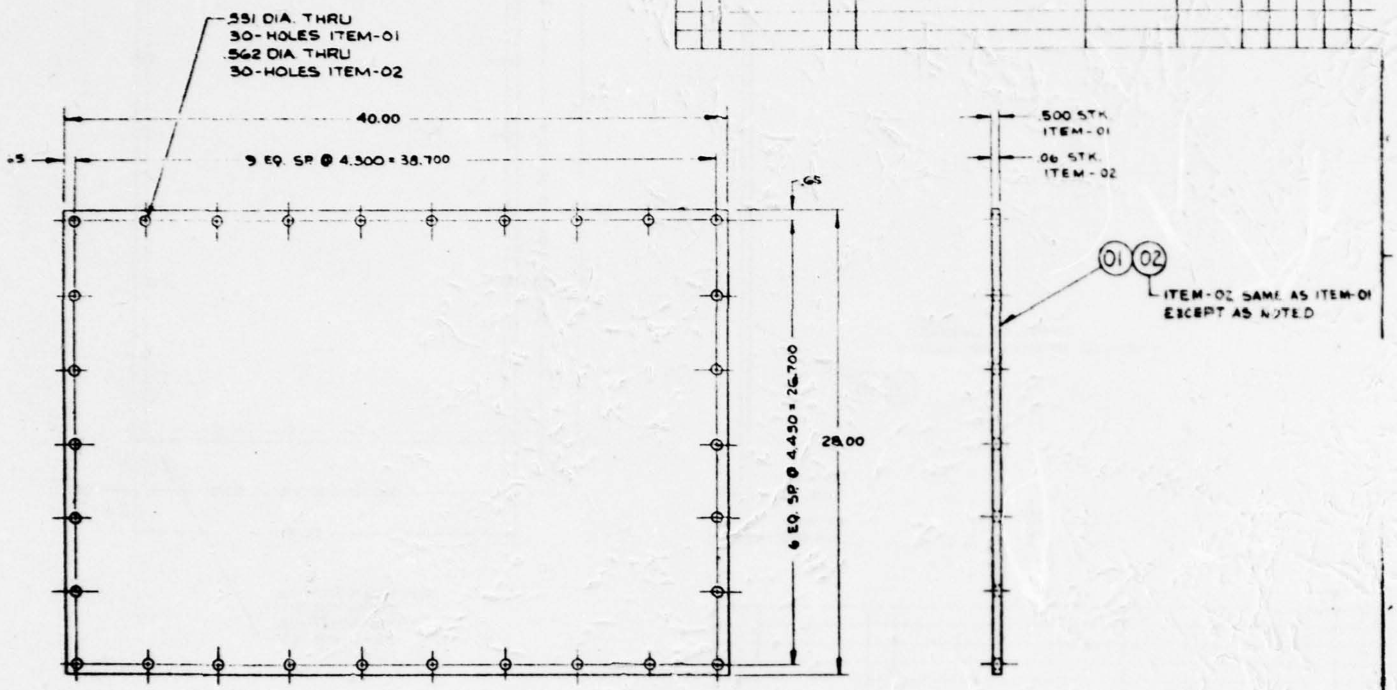
Westinghouse Electric Corporation

TITLE 3,000 H.P. 6-POLE MOTOR & 4-POLE GEN.
STUFFING TUBE MTG. PLATES-TERM. BOX
N.T.S. REV. 1
DFTR J. SABINO
2618C72

RESEARCH LABORATORIES CHURCHILL BORO PITTSBURGH PA. 15235 U.S.A.

TITLE 3,000 H.P. 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS
DWG. 2618C76 REV 1

ITEM	NOTE	PART NAME	DSP	(SIZE) REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG REQ STOCK NO.	PROCESS OR LINE NO	01	02	03	04
01		COVER		40.50 x 28.50 OF .500 THK. AL. PL.	8603-0101	6061-T651	1			
02		GASKET		40.50 x 28.50 OF .06 THK BUNA"N" SH.	PD545351EL		1			

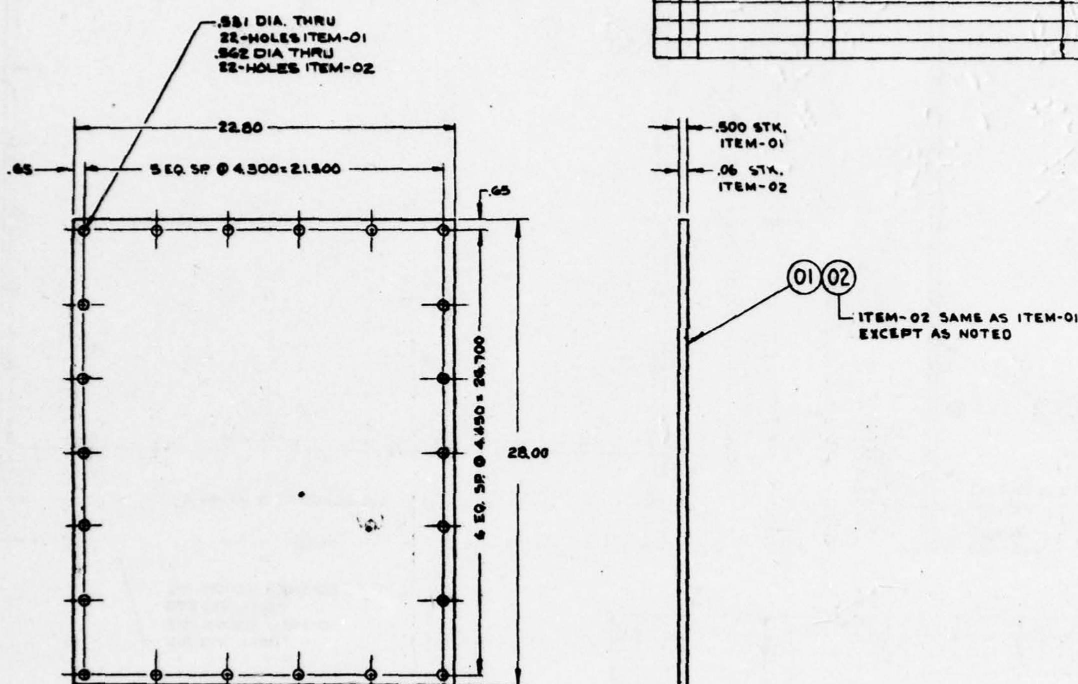


Westinghouse Electric Corporation
TITLE 3,000 H.P. 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS
1:4 REV. 1
1289J56
1289J53
2618C76
RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH PA.

TITLE 3000 H.P., 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS

DWG 2618C77 REV 1

ITEM	NOTE	PART NAME	DEF	(SIZE) REFERENCE INFORMATION	MATL SIZE CODE PART NUMBER OR REF DWG R&D STOCK NO	GROUP NOTE / PROCESS OR LINE NO	GROUP 01	02	03	04	05
01		COVER		28.50 x 23.30 OF .500 THK. AL. PL.	8603-0101	6061-T651	1				
02		GASKET		28.50 x 23.30 OF .06 THK. BUNA "N" SH.	PDS4535IEL		1				



Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR & 4-POLE GEN.
TERMINAL BOX COVER & GASKET DETAILS

SCALE 1:4 REV. 1

1289J56
1289J53

2618C77

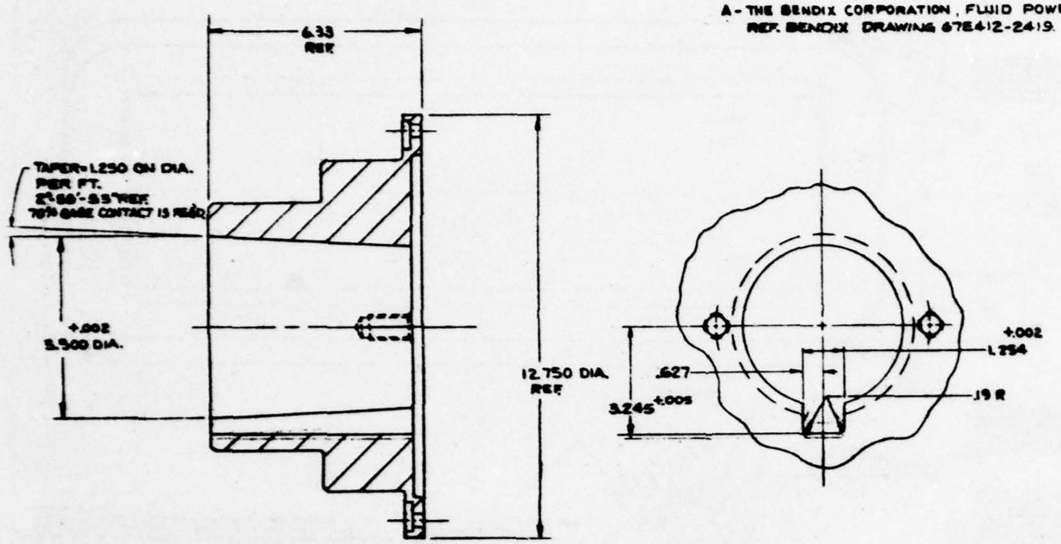
RESEARCH LABORATORIES

TITLE 3,000 H.P., 6-POLE MOTOR
HUB DRIVER MODIFICATION - ROTOR

DWG 2619C01 REV 1

ITEM	NOTE	PART NAME	DSP	USED REFERENCE INFORMATION	MAT'L SIZE CODE PART NUMBER OR REF DWG	GROUP NOTE PROCESS OR LINE NO	GROUP 01	02	03	04	05
01	A	HUB DRIVER	DWG		2619C01H01		1				

A - THE BENDIX CORPORATION, FLUID POWER DIVISION, UTICA, NEW YORK.
REF. BENDIX DRAWING 67E412-2419.



Westinghouse Electric Corporation

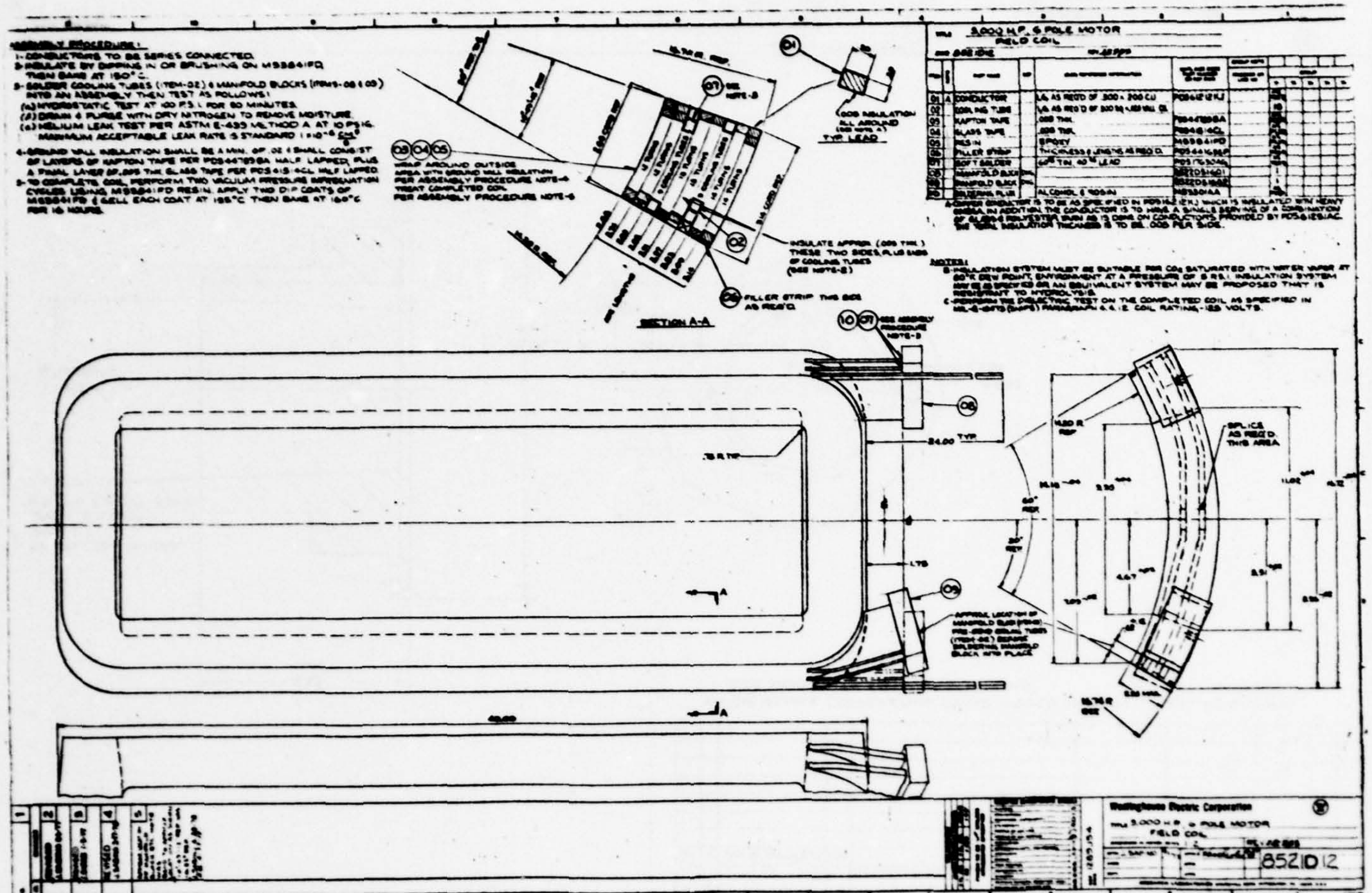
TITLE 3,000 H.P., 6-POLE MOTOR
HUB DRIVER MODIFICATION - ROTOR

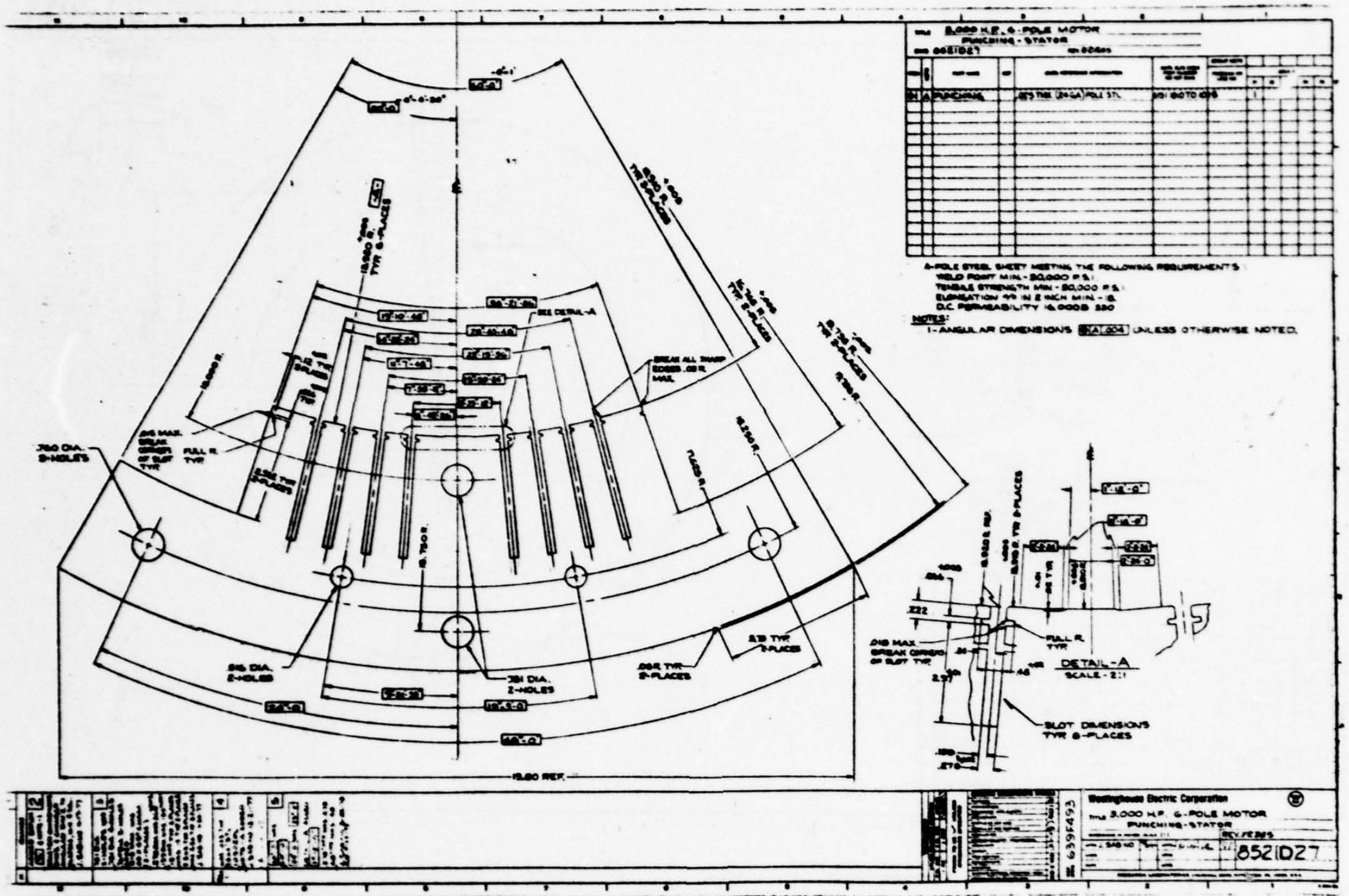
SCALE 1:2 REV 1

DFTR T. GRADISEK

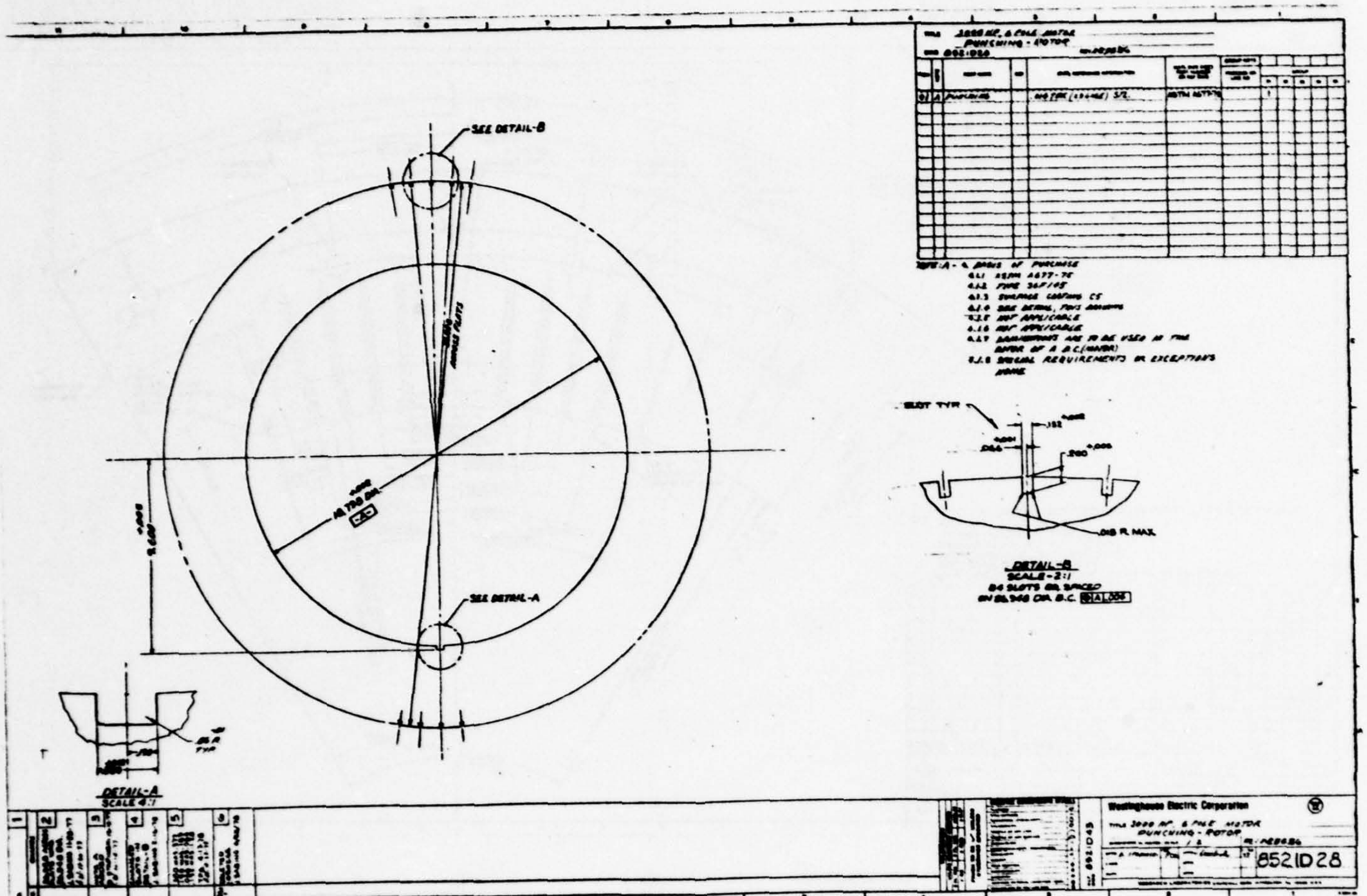
2619C01

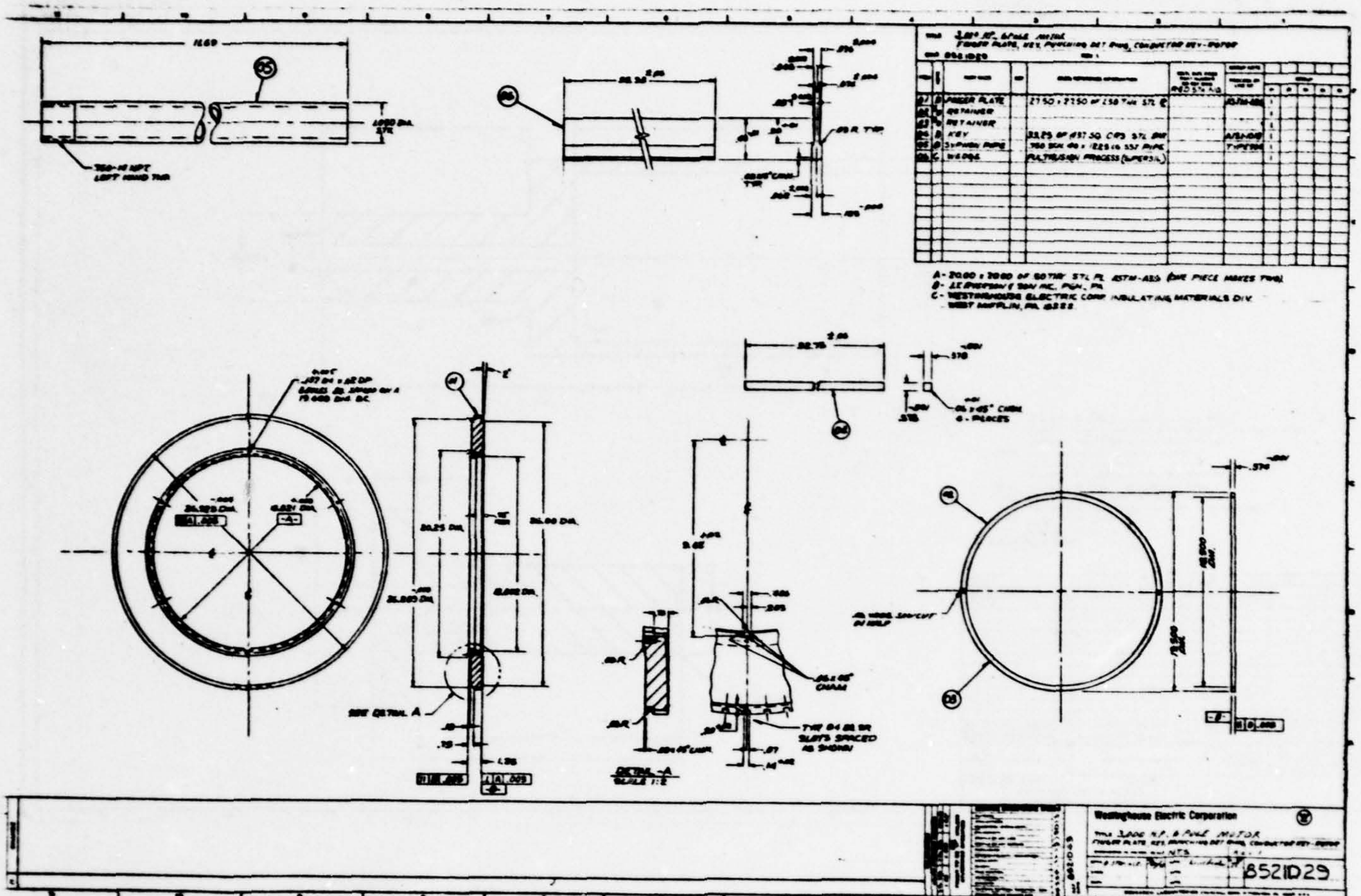
1289J56


ASSEMBLY PROCEDURE:
1- CONDUCTORS TO BE SERIES CONNECTED.
2- INSULATE BY DIPPING IN OR BRUSHING ON M53841FQ THEN BAKE AT 150°C.
3- SOLDER COOLING TUBES (ITEM-02) & MANIFOLD BLOCKS (ITEMS-08 & 09) INTO AN ASSEMBLY THEN TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 P.S.I. FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST PER ASTM E-499 METHOD A AT 10 PSIG. MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD 1×10⁻⁶ CM³/S
4- GROUND WALL INSULATION SHALL BE A MIN. OF .02 & SHALL CONSIST OF LAYERS OF KAPTON TAPE PER PDS44789BA HALF LAPPED, PLUS A FINAL LAYER OF .005 THK GLASS TAPE PER PDS41514CL HALF LAPPED.
5- TO COMPLETE COIL, PERFORM TWO VACUUM PRESSURE IMPREGNATION CYCLES USING M53841FD RESIN. APPLY TWO DIP COATS OF M53841FD & GELL EACH COAT AT 135°C THEN BAKE AT 160°C FOR 16 HOURS.
WRAP AROUND OUTSIDE AREA WITH GROUND WALL INSULATION PER ASSEMBLY PROCEDURE NOTE-4
TREAT COMPLETED COIL PER ASSEMBLY PROCEDURE NOTE-5
TYP. LEAD
INSULATE APPROX (.005 THK.) THESE TWO SIDES, PLUS ENDS OF COOLING TUBES
FILLER STRIP TWO SIDE AS REQ'D.
SECTION A-A
3,000 H.P., 6 POLE MOTOR
FIELD COIL
01 A CONDUCTOR
02 COOLING TUBE
03 KAPTON TAPE .005 THK.
04 GLASS TAPE .005 THK.
05 RESIN EPOXY
06 FILLER STRIP THICKNESS & LENGTHS AS REQ'D.
07 SOFT SOLDER 60% TIN, 40% LEAD
08 MANIFOLD BLOCK
09 MANIFOLD BLOCK
10 SOLDERING FLUX ALCOHOL & ROSIN
THE TOTAL INSULATION THICKNESS IS TO BE .005 PER SIDE.
NOTES:
B- INSULATION SYSTEM MUST BE SUITABLE FOR CO2 SATURATED WITH WATER VAPOR AT 60°F DEW POINT, ENVIRONMENT AT A PRESSURE OF 5 P.S.I. INSULATION SYSTEM MAY BE AS SPECIFIED OR AN EQUIVALENT SYSTEM MAY BE PROPOSED THAT IS RESISTANT TO HYDROLYSIS.
C- PERFORM THE DIELECTRIC TEST ON THE COMPLETED COIL AS SPECIFIED IN MIL-E-917D (SHIPS) PARAGRAPH 4.4.12. COIL RATING - 125 VOLTS.
SEE ASSEMBLY PROCEDURE NOTE-3
SPLICE AS REQ'D. THIS AREA
24.00 TYP
1.75
40.00
Westinghouse Electric Corporation
3,000 H.P. 6 POLE MOTOR
FIELD COIL
852D12

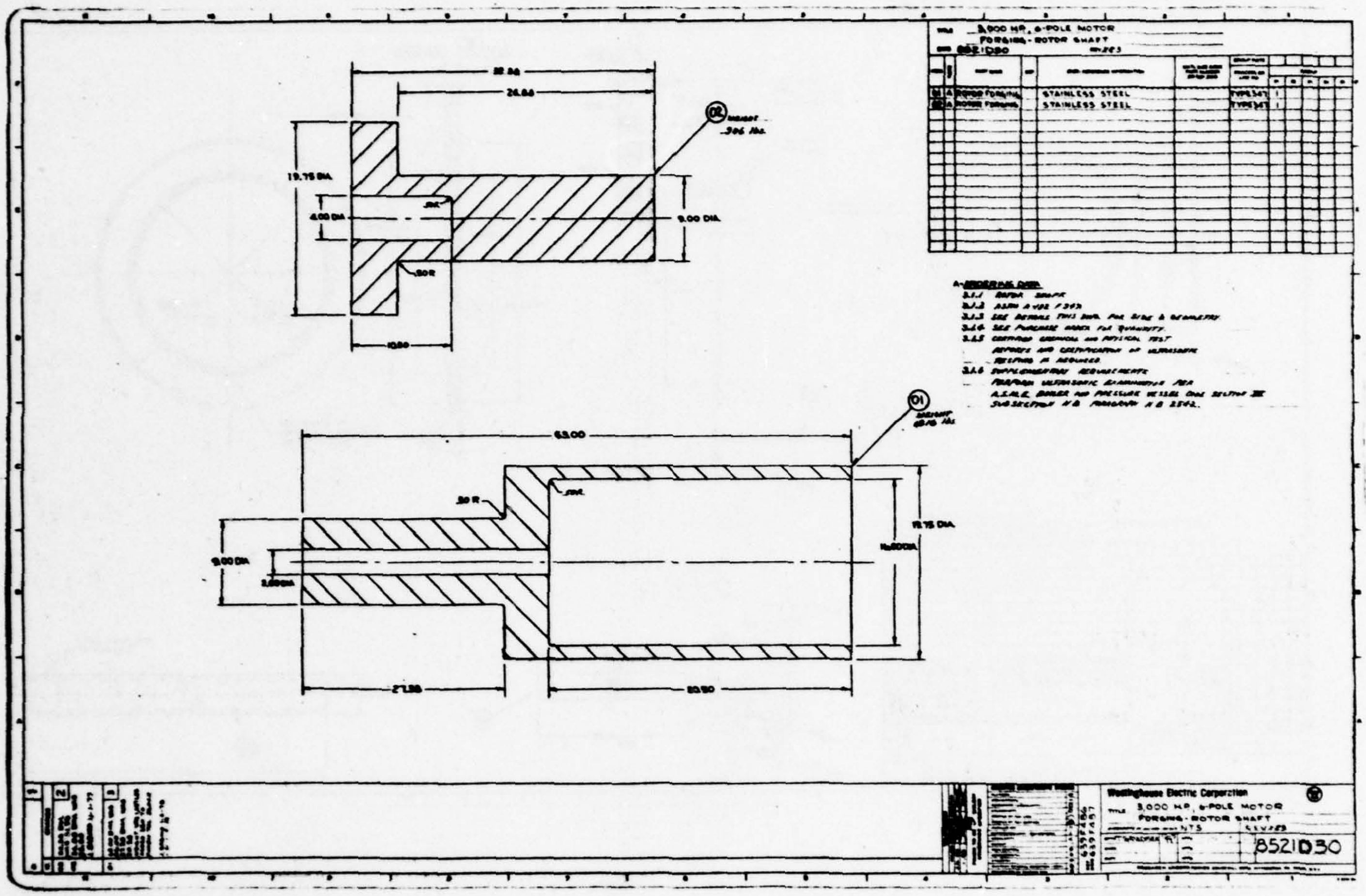


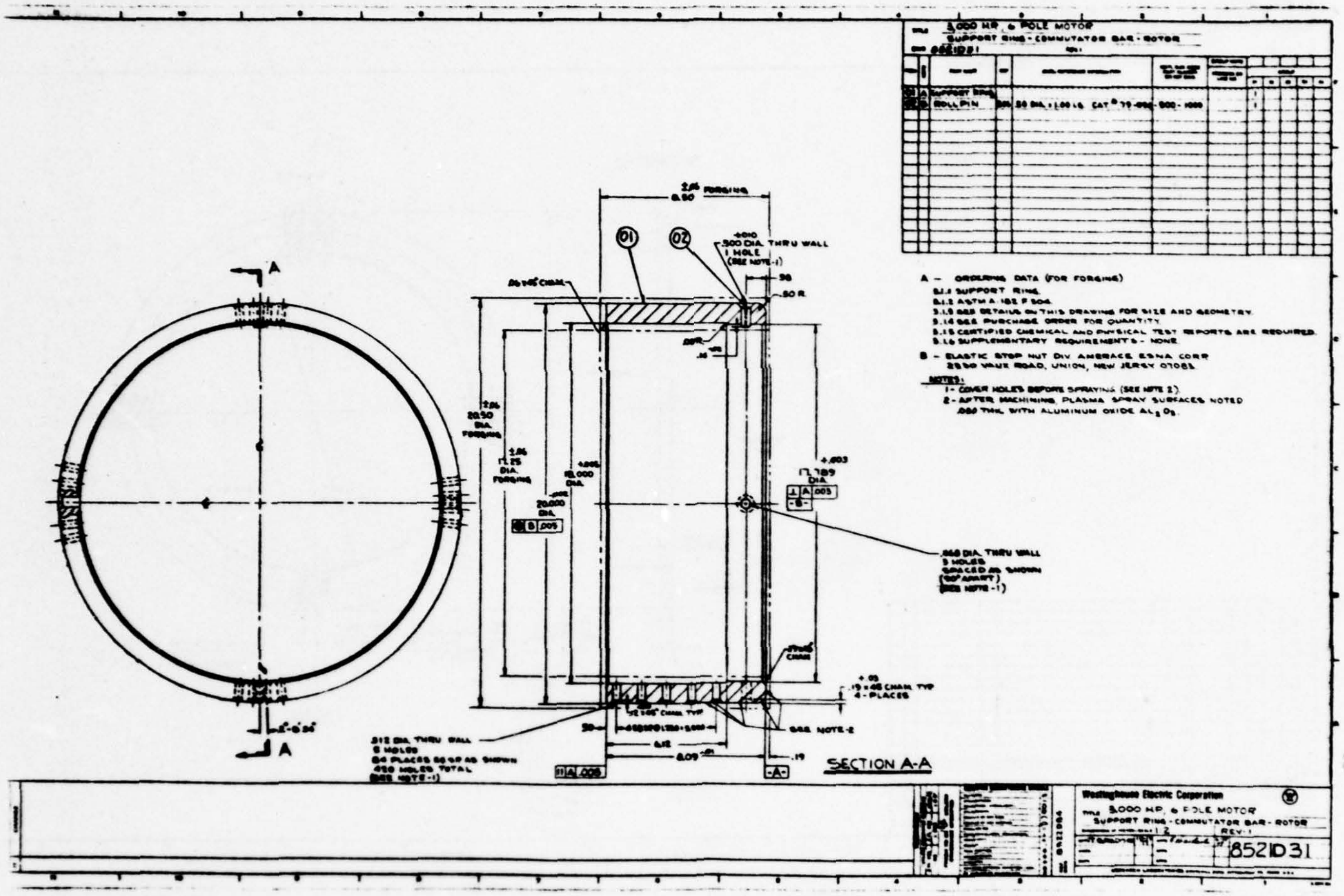
3,000 H.P. 6-POLE MOTOR
PUNCHING - STATOR
PUNCHING
.025 THK (24GA) POLE STL
A-POLE STEEL SHEET MEETING THE FOLLOWING REQUIREMENTS:
YIELD POINT MIN. - 30,000 P.S.I.
TENSILE STRENGTH MIN. - 50,000 P.S.I.
D.C. PERMEABILITY 16,000B 330
NOTES:
1-ANGULAR DIMENSIONS UNLESS OTHERWISE NOTED.
SEE DETAIL-A
BREAK ALL SHARP EDGES
.760 DIA. 2-HOLES
.516 DIA. 2-HOLES
.781 DIA. 2-HOLES
FULL R. TYP
19.750 R.
15.250 R.
.098 TYP 2-PLACES
2.13 TYP 2-PLACES
DETAIL-A
SCALE - 2:1
SLOT DIMENSIONS
TYP 6-PLACES
Westinghouse Electric Corporation
TITLE 3,000 H.P. 6-POLE MOTOR
PUNCHING - STATOR
639F493
852ID27

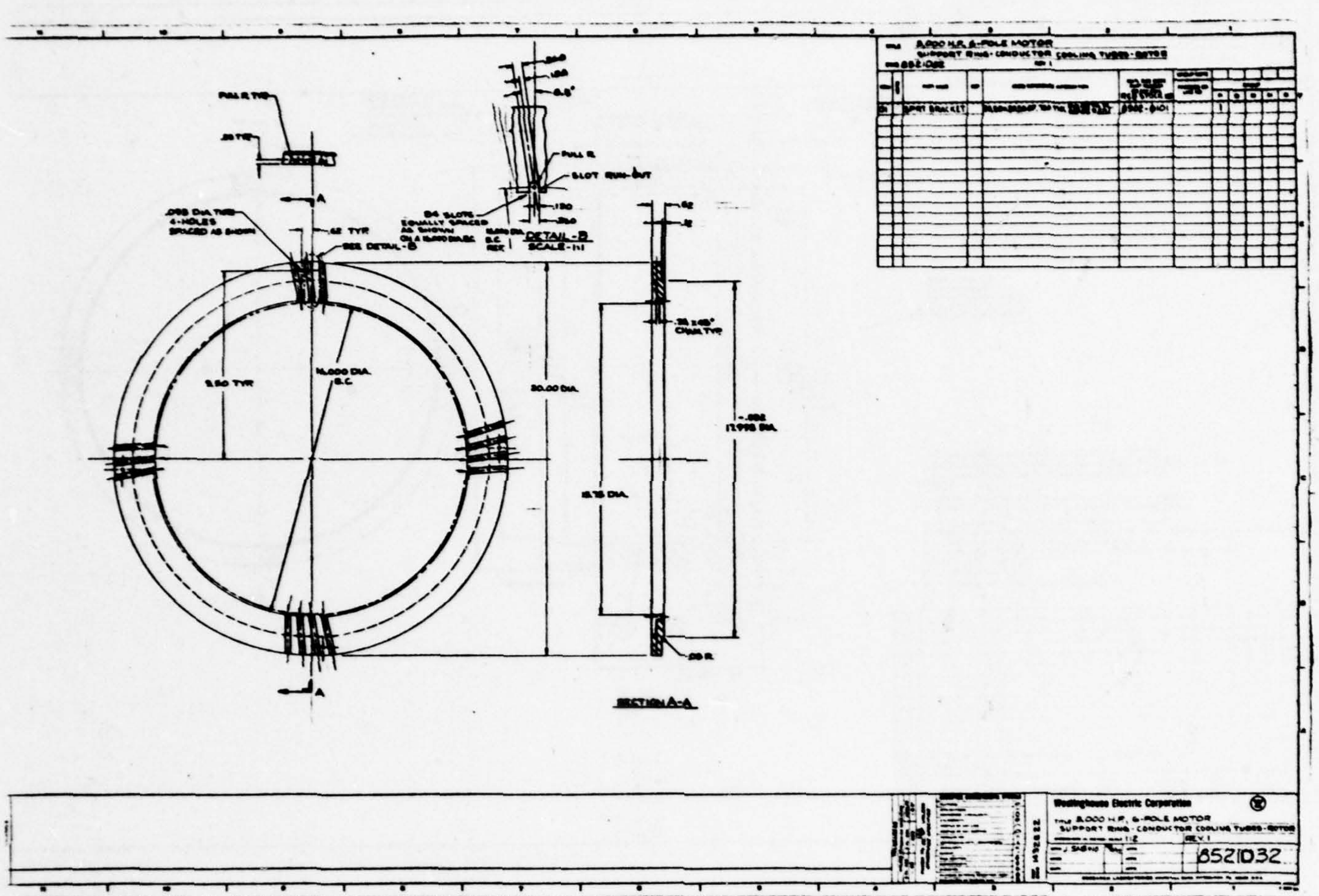

SEE DETAIL-B
SEE DETAIL-A
DETAIL-A
SCALE 4:1
DETAIL-B
SCALE-2:1
SLOT TYP
.018 R. MAX.
Westinghouse Electric Corporation
8521D28



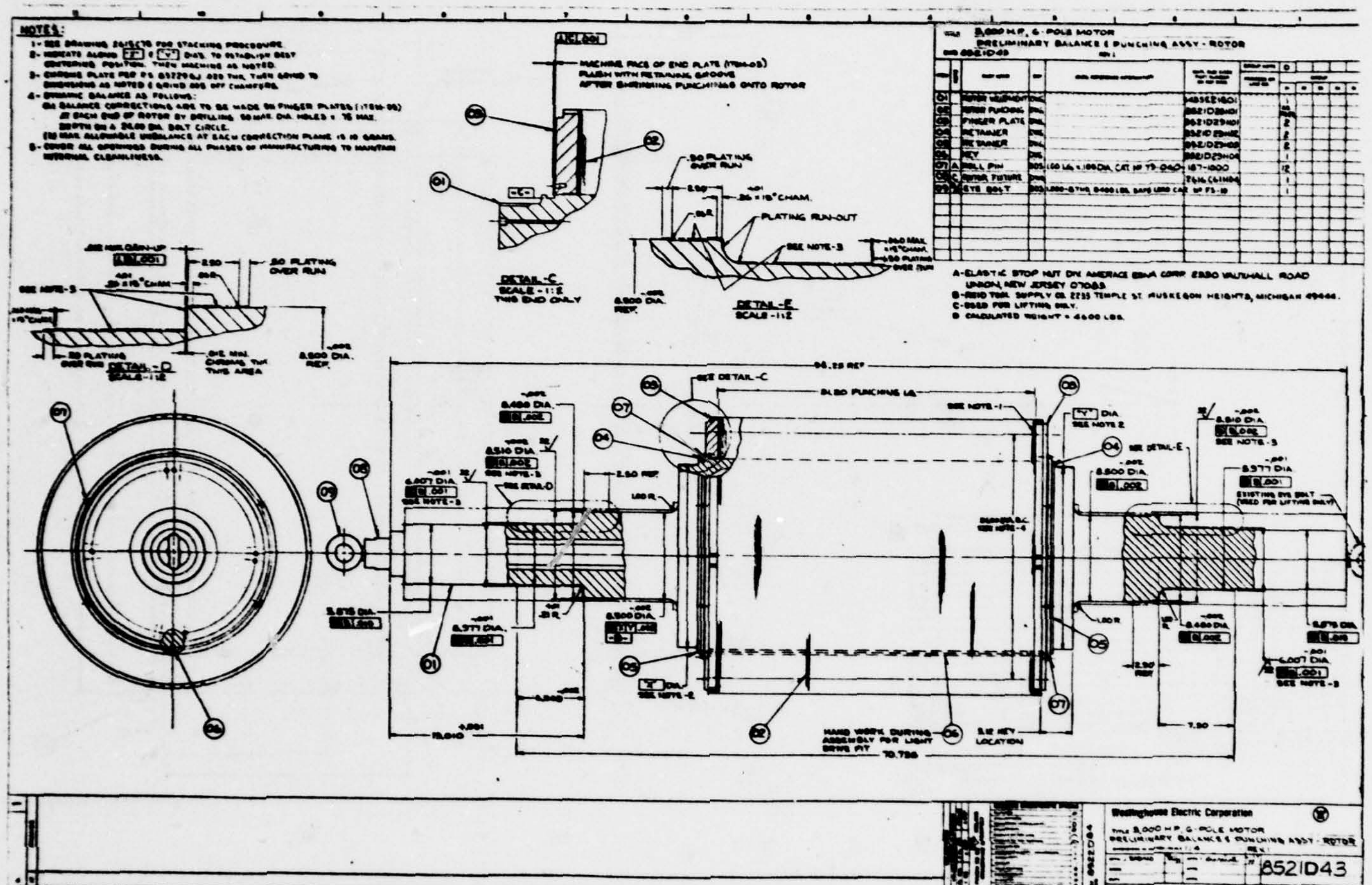
11.69
LEFT HAND THD
FINGER PLATE
RETAINER
RETAINER
KEY
WEDGE
2750 x 2750 OF .250 THK STL
PULTRUSION PROCESS (SUPERSIL)
A - 20.00 x 20.00 OF .50 THK STL PL ASTM-A36 (ONE PIECE MAKES TWO)
C - WESTINGHOUSE ELECTRIC CORP INSULATING MATERIALS DIV.
WEST MIFFLIN, PA
SEE DETAIL A
DETAIL - A
SCALE 1:2
Westinghouse Electric Corporation
3000 H.P. 6 POLE MOTOR
NTS
8521D29

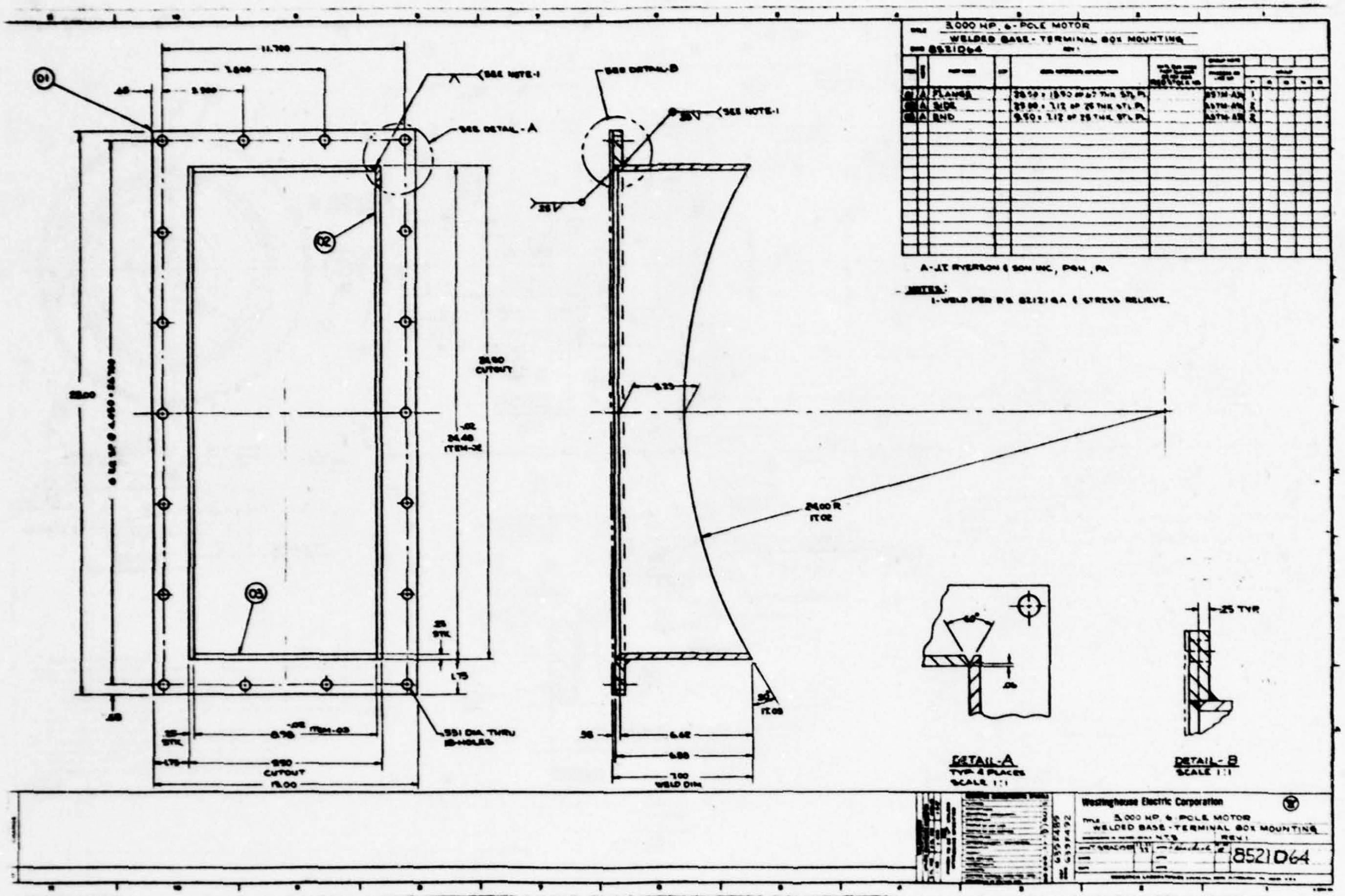

3,000 HP, 6-POLE MOTOR
FORGING - ROTOR SHAFT
STAINLESS STEEL
STAINLESS STEEL
WEIGHT .306 lbs.
WEIGHT
38.94
24.84
19.75 DIA.
4.00 DIA.
9.00 DIA.
.50 R
10.80
63.00
.50 R
9.00 DIA.
19.75 DIA.
27.38
30.50
A.S.M.E. BOILER AND PRESSURE VESSEL CODE SECTION III
Westinghouse Electric Corporation
TITLE 3,000 HP, 6-POLE MOTOR
FORGING - ROTOR SHAFT
NTS
8521D30

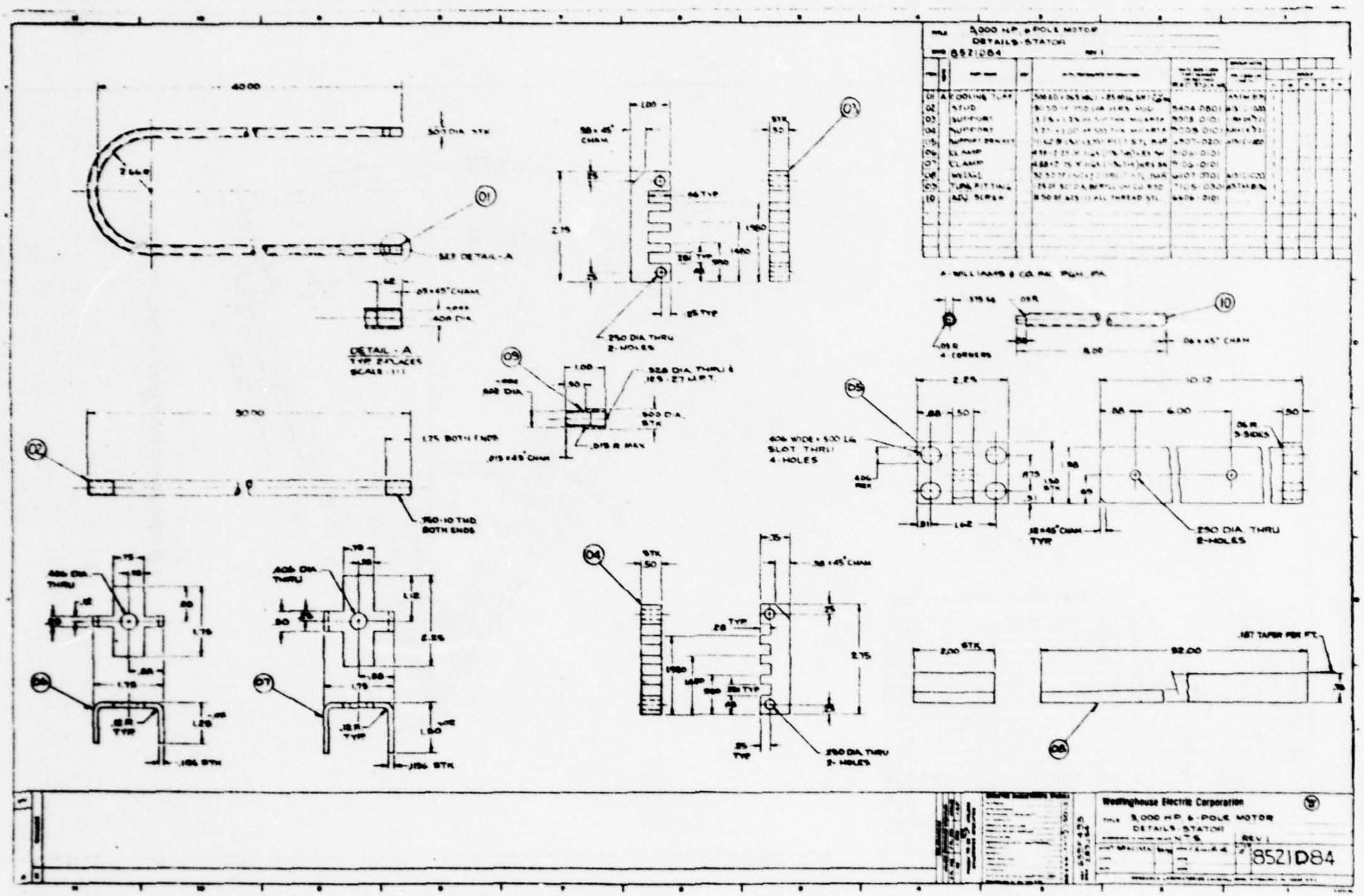

5,000 H.P. 6 POLE MOTOR
SUPPORT RING - COMMUTATOR BAR - ROTOR
SUPPORT RING
ROLLPIN
A - ORDERING DATA (FOR FORGING)
SUPPORT RING.
ASTM A 182 F 304.
SEE DETAILS ON THIS DRAWING FOR SIZE AND GEOMETRY.
SEE PURCHASE ORDER FOR QUANTITY.
CERTIFIED CHEMICAL AND PHYSICAL TEST REPORTS ARE REQUIRED.
SUPPLEMENTARY REQUIREMENTS - NONE.
B - ELASTIC STOP NUT DIV AMERACE ESNA CORP
2330 VAUX ROAD, UNION, NEW JERSEY 07083
NOTES:
1 - COVER HOLES BEFORE SPRAYING (SEE NOTE 2).
2 - AFTER MACHINING, PLASMA SPRAY SURFACES NOTED
WITH ALUMINUM OXIDE AL2O3.
SECTION A-A
Westinghouse Electric Corporation
5,000 H.P. 6 POLE MOTOR
SUPPORT RING - COMMUTATOR BAR - ROTOR
8521D31



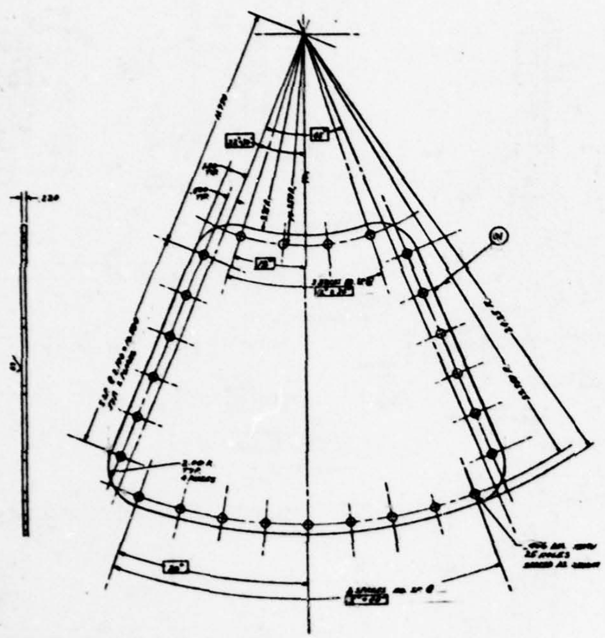
8,000 H.P. 6-POLE MOTOR
SUPPORT RING - CONDUCTOR COOLING TUBES - ROTOR
FULL R. TYP
.098 DIA. THRU
4-HOLES
SPACED AS SHOWN
.62 TYP
SEE DETAIL-B
84 SLOTS
EQUALLY SPACED
AS SHOWN
DETAIL-B
SCALE-1:1
FULL R.
SLOT RUN-OUT
9.50 TYP
16.000 DIA.
B.C.
20.00 DIA.
15.75 DIA.
12.998 DIA.
.03 R.
A
SECTION A-A
Westinghouse Electric Corporation
TITLE 8,000 H.P., 6-POLE MOTOR
SUPPORT RING - CONDUCTOR COOLING TUBES - ROTOR
1:2
REV. 1
J. SABINO
6521D32


NOTES:
3,000 H.P. 6-POLE MOTOR
PRELIMINARY BALANCE & PUNCHING ASSY - ROTOR
MACHINE FACE OF END PLATE
FLUSH WITH RETAINING GROOVE
AFTER SHRINKING PUNCHINGS ONTO ROTOR
.30 PLATING OVER RUN
PLATING RUN-OUT
SEE NOTE-3
DETAIL-C
SCALE-1:2
THIS END ONLY
DETAIL-E
SCALE-1:2
DETAIL-D
SCALE-1:2
8.500 DIA. REF.
A-ELASTIC STOP NUT ON AMERACE ESNA CORP. 2330 VAUXHALL ROAD UNION, NEW JERSEY 07083
B-REID TOOL SUPPLY CO. 2235 TEMPLE ST. MUSKEGON HEIGHTS, MICHIGAN 49444
C-USED FOR LIFTING ONLY.
D-CALCULATED WEIGHT = 4600 LBS.
SEE DETAIL-C
SEE DETAIL-E
SEE DETAIL-D
PUNCHING LG.
SEE NOTE-1
SEE NOTE-2
SEE NOTE-3
EXISTING EYE BOLT (USED FOR LIFTING ONLY)
HAND WORK DURING ASSEMBLY FOR LIGHT DRIVE FIT
KEY LOCATION
70.730
6.400 DIA.
8.510 DIA.
8.500 DIA.
6.377 DIA.
6.007 DIA.
5.875 DIA.
Westinghouse Electric Corporation
8521D43


3,000 HP. 6-POLE MOTOR
WELDED BASE - TERMINAL BOX MOUNTING
8521D64
FLANGE
SIDE
END
A-J.T. RYERSON & SON INC., PGH., PA.
NOTES:
1-WELD PER P.S. 8212GA & STRESS RELIEVE.
SEE NOTE-1
SEE DETAIL-A
SEE DETAIL-B
11.700
7.800
3.900
26.00
21.50
CUTOUT
24.48
24.00 R
.25 TYP
.551 DIA. THRU
1.75
9.50
CUTOUT
15.00
7.00
WELD DIM.
DETAIL-A
TYP. 4 PLACES
SCALE 1:1
DETAIL-B
SCALE 1:1
Westinghouse Electric Corporation
3,000 HP. 6-POLE MOTOR
WELDED BASE - TERMINAL BOX MOUNTING
8521D64



5,000 H.P. 6-POLE MOTOR
DETAILS-STATOR
8521D84
DETAIL - A
TYP 2 PLACES
SCALE 1:1
SEE DETAIL-A
.250 DIA THRU
2-HOLES
.190-10 THD
BOTH ENDS
1.75 BOTH ENDS
A. WILLIAMS & CO. PH. PGH. PA.
.406 WIDE x .500 LG
SLOT THRU
4-HOLES
.250 DIA. THRU
2-HOLES
.187 TAPER PER FT.
Westinghouse Electric Corporation
5,000 H.P. 6-POLE MOTOR
DETAILS-STATOR
8521D84



TITLE 3,000 H.P., 6 POLE MOTOR
BRUSH ACCESS COVER DETAIL
8521D85

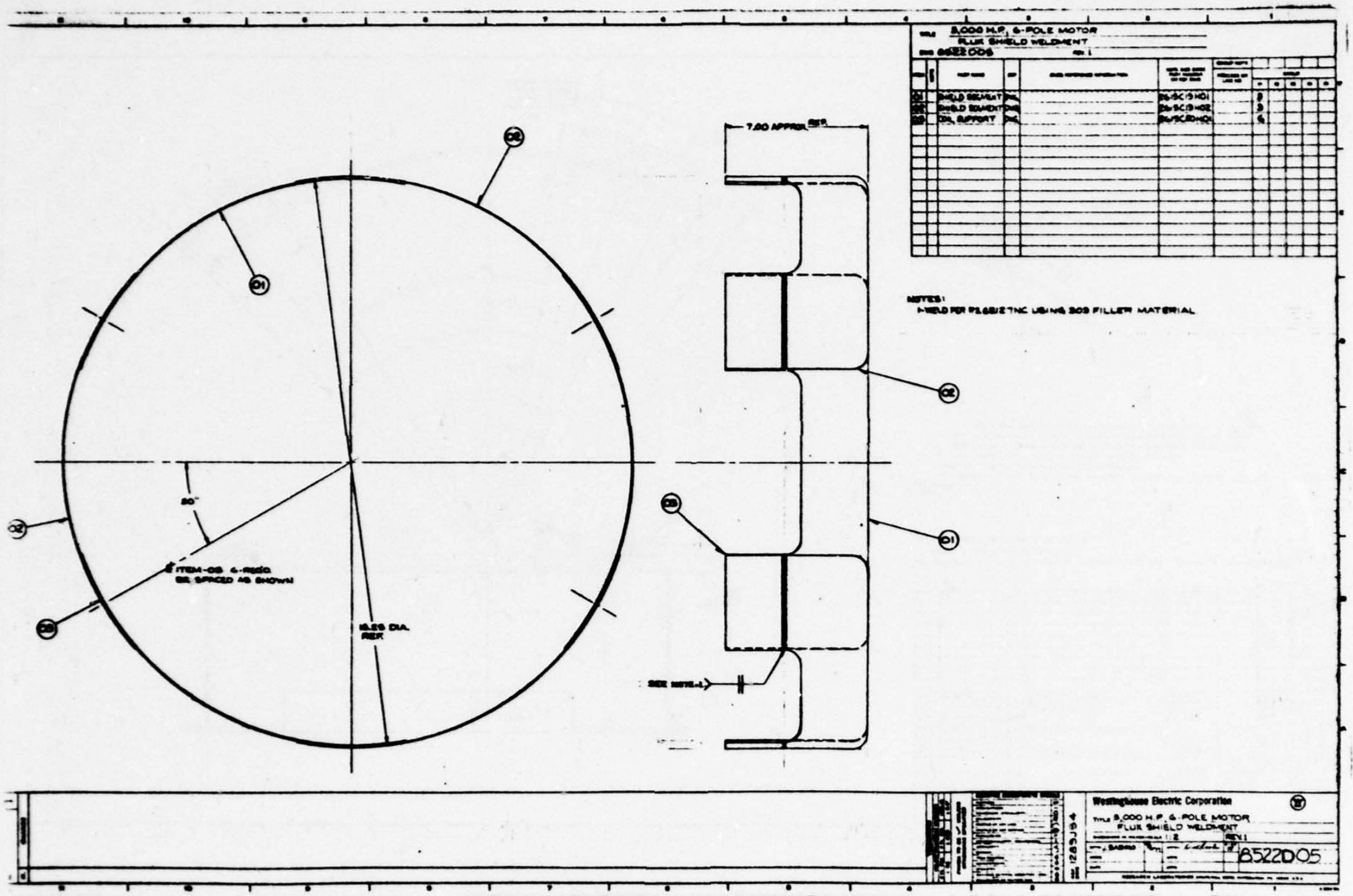
D1	A	COVER PLATE		[illegible] .250 [illegible]		[illegible]	1

NOTE: A - S.T. [illegible]

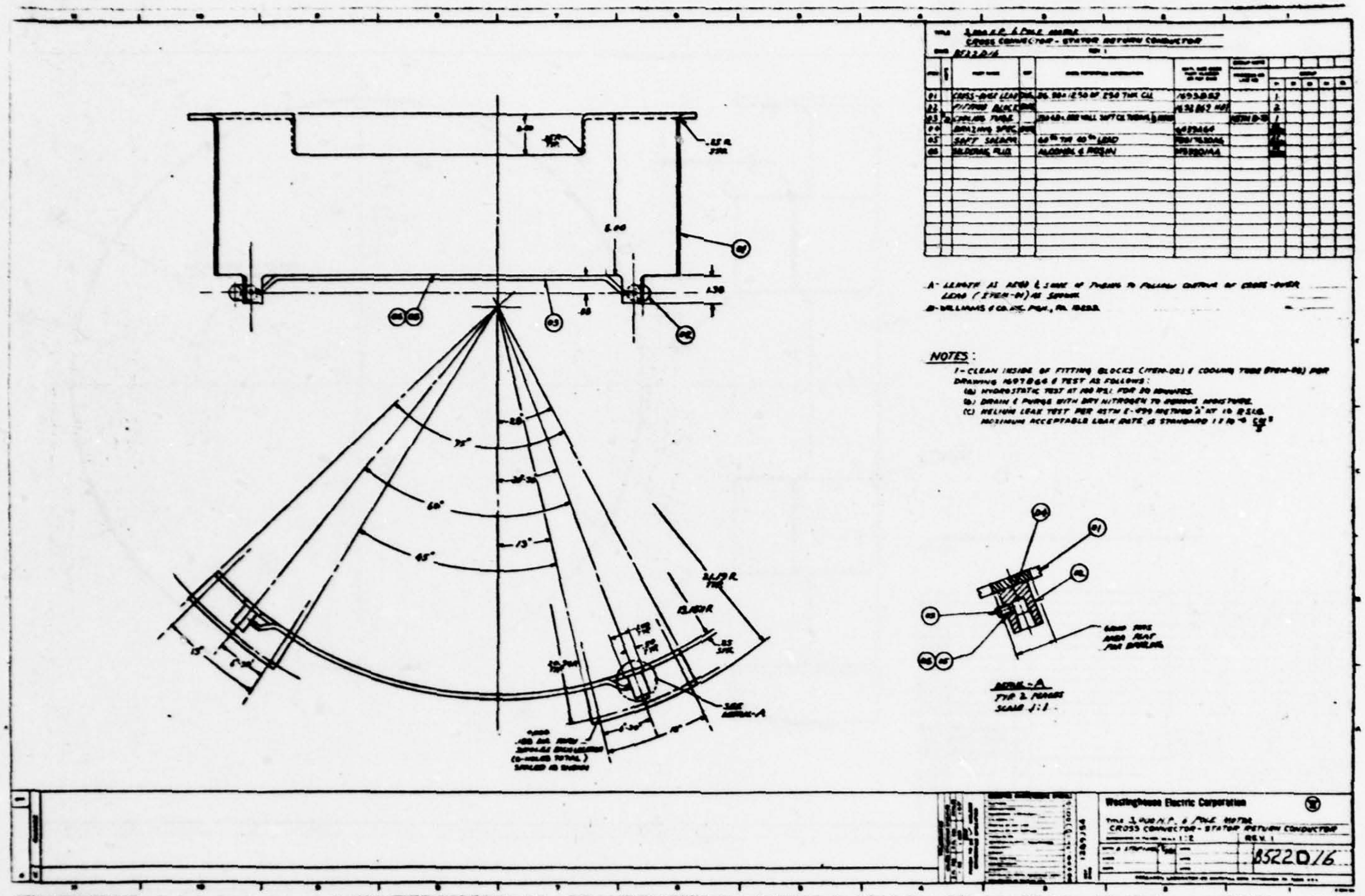
Westinghouse Electric Corporation

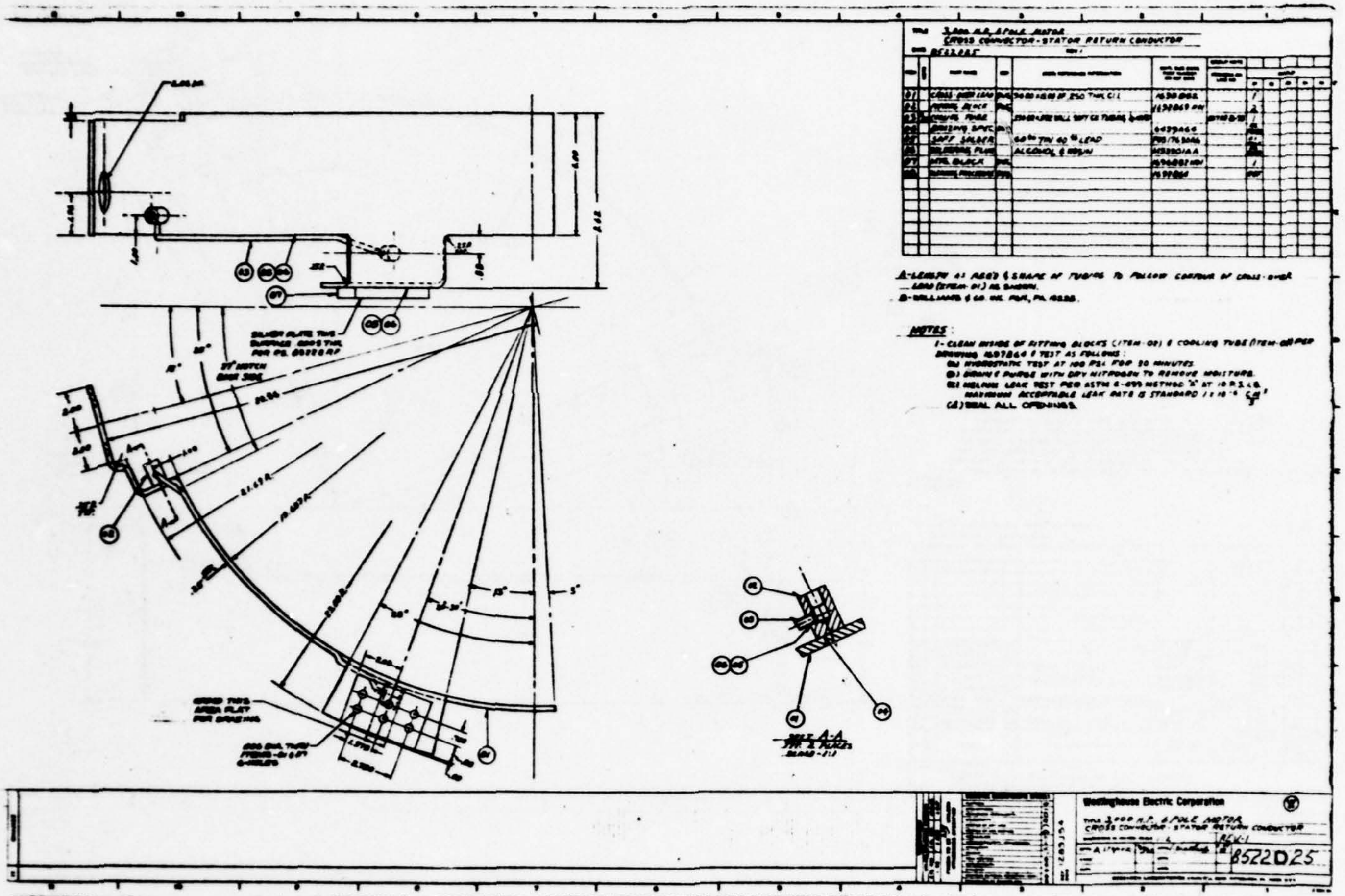
TITLE 3,000 H.P., 6 POLE MOTOR
BRUSH ACCESS COVER DETAIL
REV. 1

8521D85

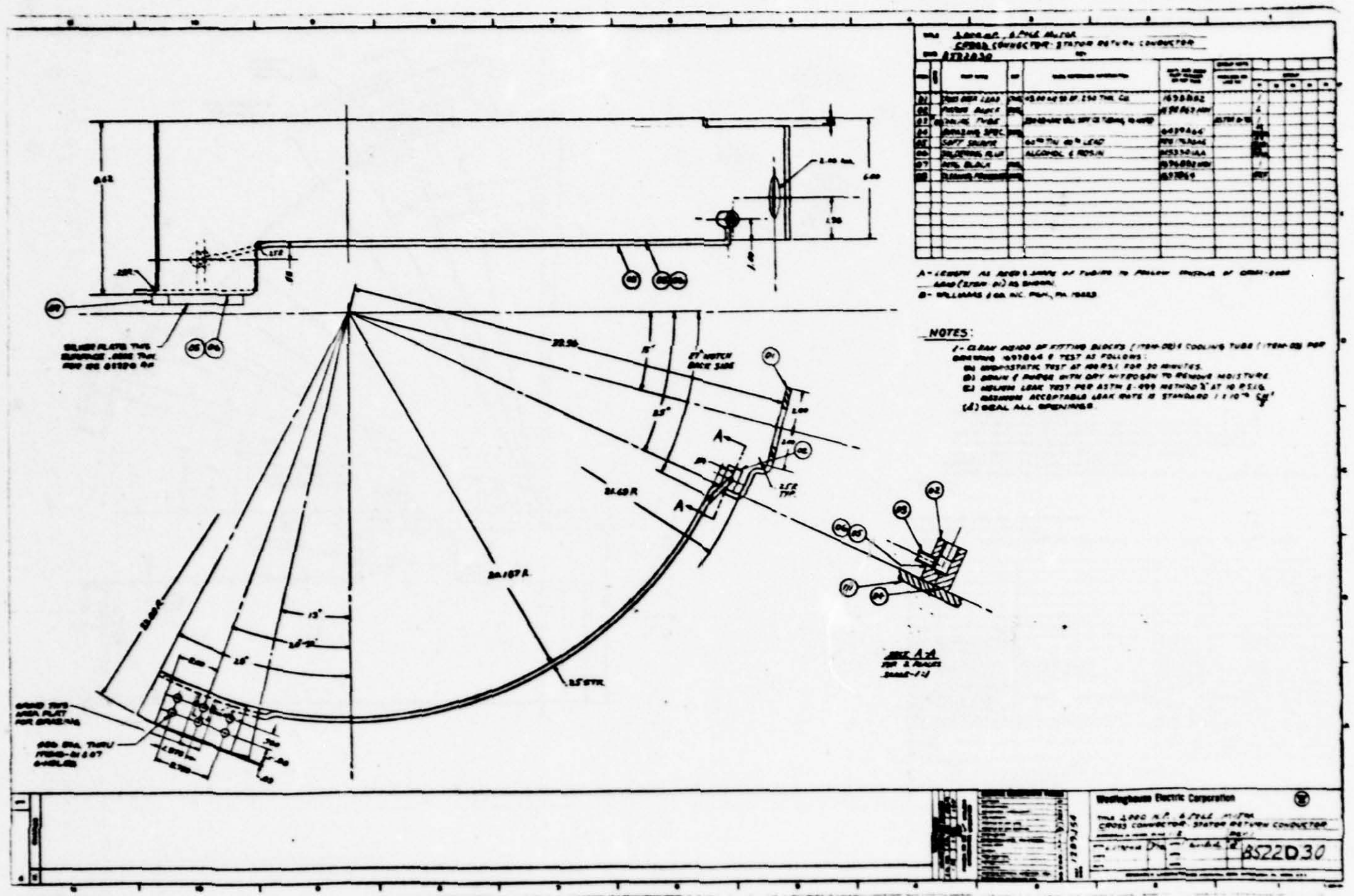

5,000 H.P. 6-POLE MOTOR
FLUX SHIELD WELDMENT
SHIELD SEGMENT
SHIELD SEGMENT
COIL SUPPORT
NOTES:
1-WELD PER P5.6812 THC USING 308 FILLER MATERIAL
7.00 APPROX. REF.
SEE NOTE-1
16.25 DIA. REF.
30°
ITEM-03 6-REQD. EQ. SPACED AS SHOWN
Westinghouse Electric Corporation
TITLE 5,000 H.P. 6-POLE MOTOR
FLUX SHIELD WELDMENT
1:2
REV 1
B522D05
1289J34

71

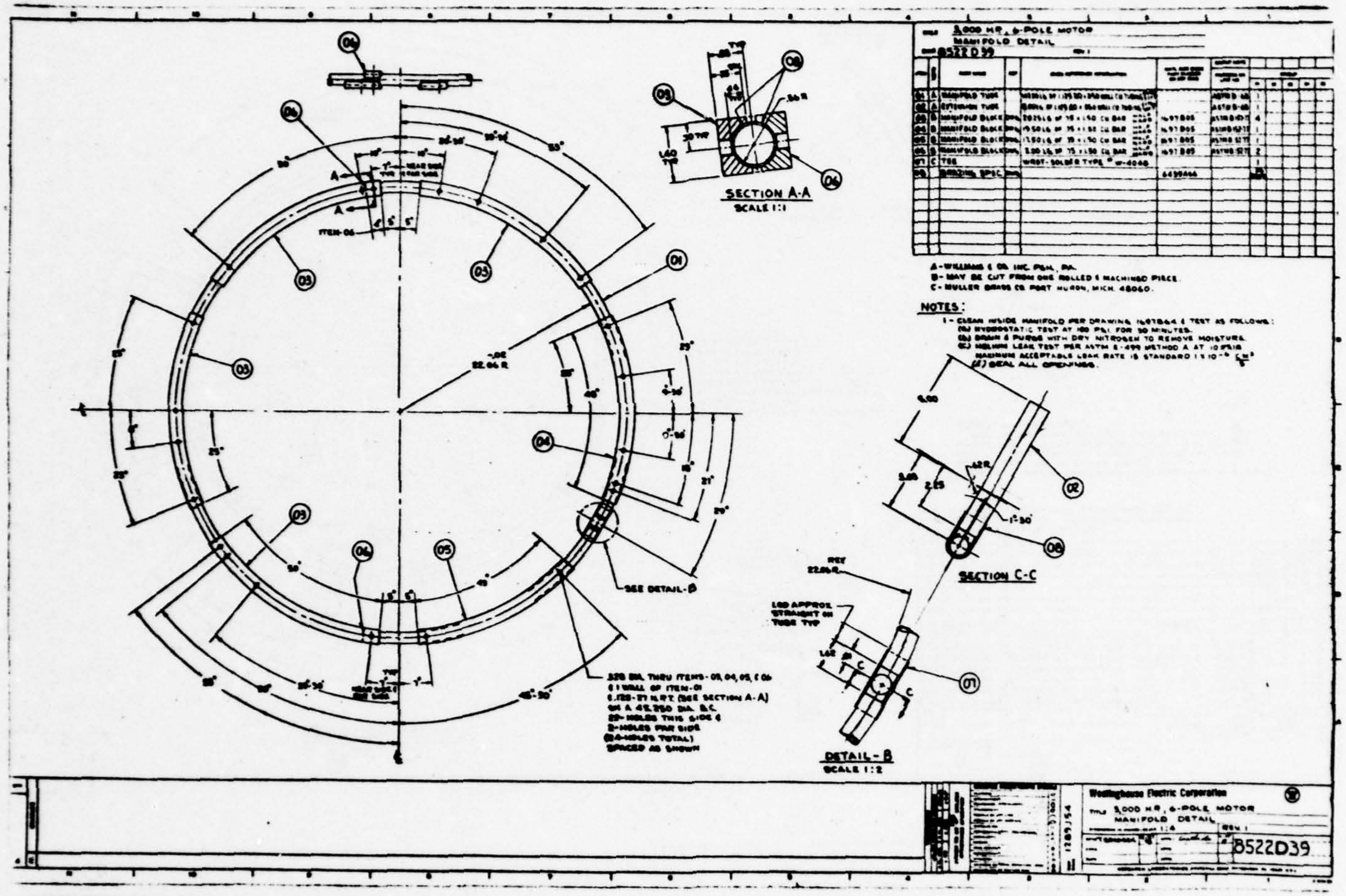

CROSS CONNECTOR - STATOR RETURN CONDUCTOR
01 CROSS-OVER LEAD
02 FITTING BLOCK
03 COOLING TUBE
04 BRAZING SPEC.
05 SOFT SOLDER
06 SOLDERING FLUX
ALCOHOL & ROSIN
NOTES:
1 - CLEAN INSIDE OF FITTING BLOCKS (ITEM-02) & COOLING TUBE (ITEM-03) PER DRAWING 1697B64 & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 PSI FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST
TYP 2 PLACES
SCALE 1:1
Westinghouse Electric Corporation
CROSS CONNECTOR - STATOR RETURN CONDUCTOR
1:2
REV. 1
8522D16
75°
60°
45°
13°
6.00

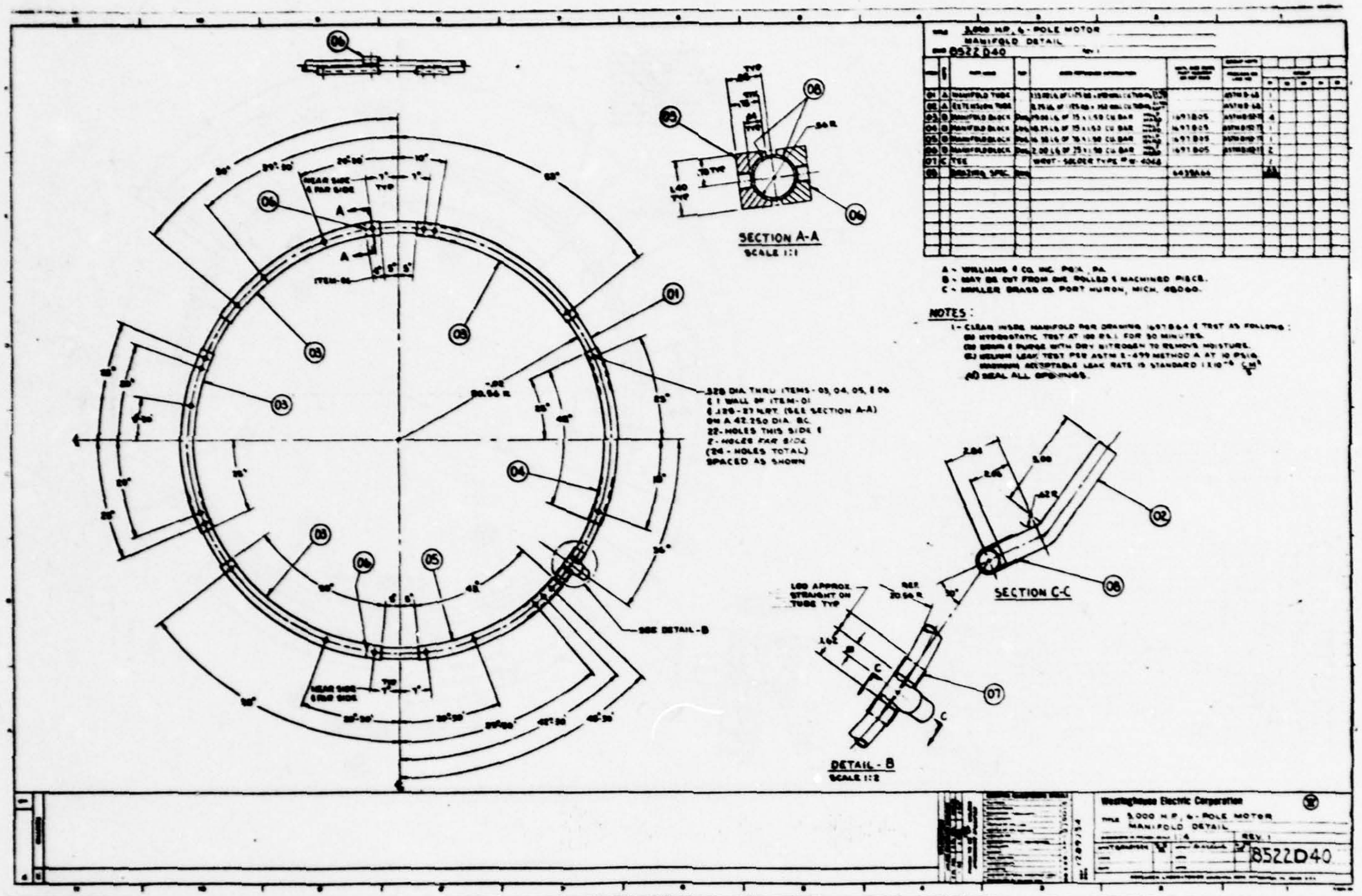


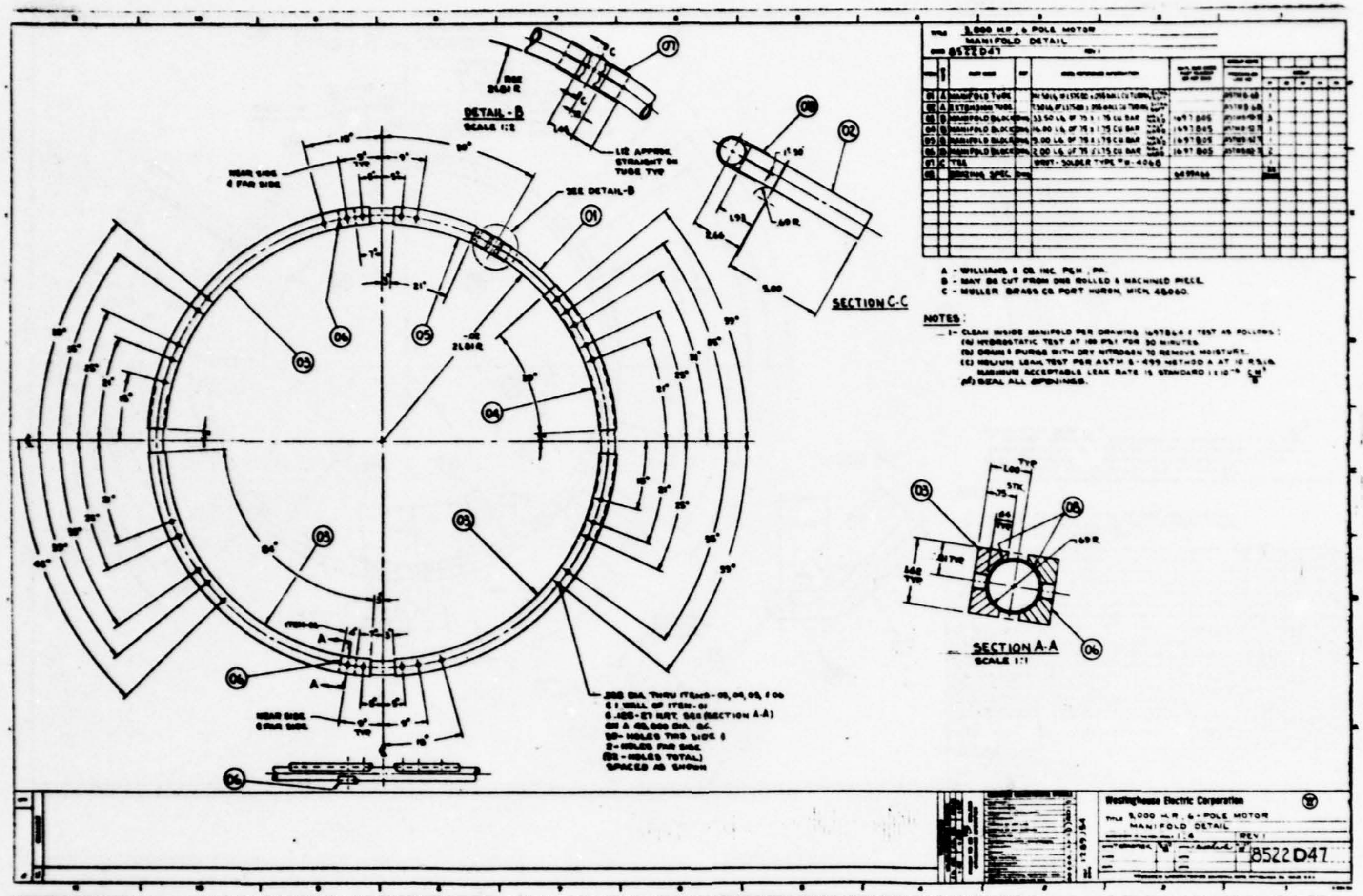
3,000 H.P. 4 POLE MOTOR
CROSS CONNECTOR - STATOR RETURN CONDUCTOR
01 CROSS-OVER LEAD
02 FITTING BLOCK
03 COOLING TUBE
04 BRAZING SPEC.
05 SOFT SOLDER — 60% TIN 40% LEAD
06 SOLDERING FLUX — ALCOHOL & ROSIN
07 MTG. BLOCK
A-LENGTH AS REQ'D & SHAPE OF TUBING TO FOLLOW CONTOUR OF CROSS-OVER LEAD (ITEM-01) AS SHOWN.
NOTES:
1- CLEAN INSIDE OF FITTING BLOCKS (ITEM-02) & COOLING TUBE (ITEM-03) PER DRAWING 4697864 & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 PSI FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST PER ASTM E-499 METHOD "A" AT 10 P.S.I.G. MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD 1 x 10⁻⁶ CM³/S
(d) SEAL ALL OPENINGS.
SILVER PLATE THIS SURFACE
SECT. A-A
Westinghouse Electric Corporation
TITLE 3,000 H.P. 4 POLE MOTOR
CROSS CONNECTOR - STATOR RETURN CONDUCTOR
REV-1
8522D25

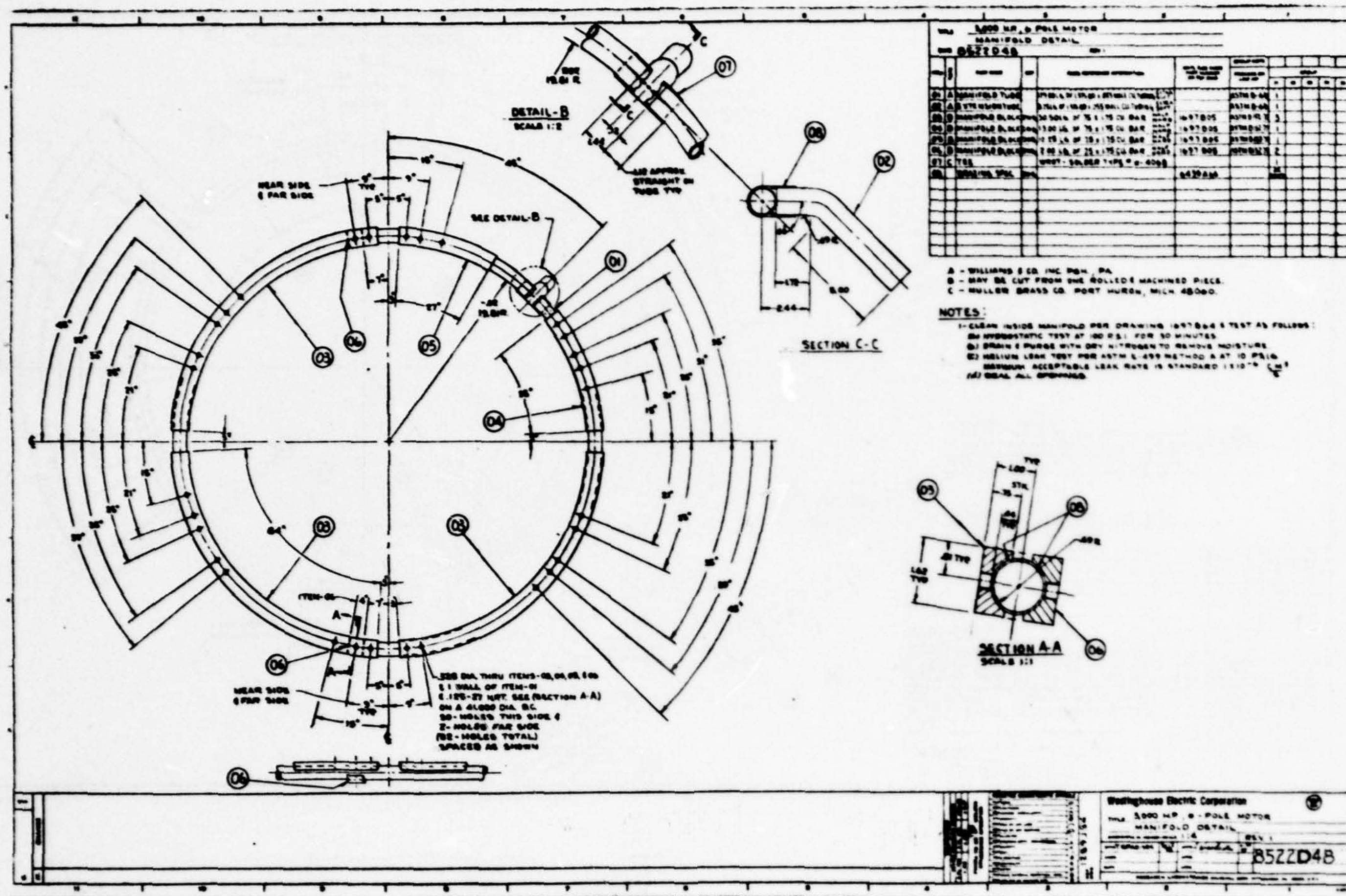


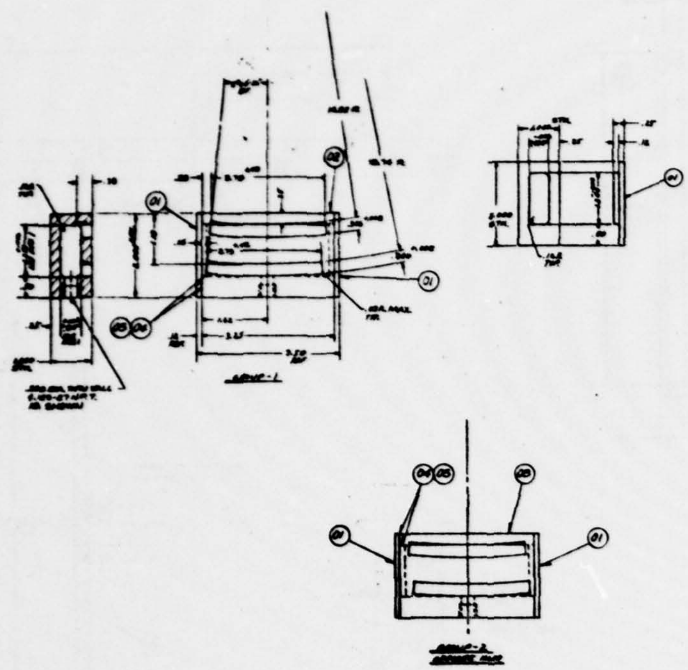
CROSS CONNECTOR - STATOR RETURN CONDUCTOR
NOTES:
(d) SEAL ALL OPENINGS
Westinghouse Electric Corporation
CROSS CONNECTOR - STATOR RETURN CONDUCTOR
8522D30


3,000 HP, 6-POLE MOTOR
MANIFOLD DETAIL
8522D39
A - WILLIAMS & CO. INC. PGH., PA.
B - MAY BE CUT FROM ONE ROLLED & MACHINED PIECE.
C - MULLER BRASS CO. PORT HURON, MICH. 48060.
NOTES:
1 - CLEAN INSIDE MANIFOLD PER DRAWING & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 PSI FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST PER ASTM E-499 METHOD A AT 10 PSIG
MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD 1 x 10⁻⁶ CM³/S
(d) SEAL ALL OPENINGS.
SECTION A-A
SCALE 1:1
SECTION C-C
DETAIL - B
SCALE 1:2
SEE DETAIL - B
22.06 R
1.00 APPROX STRAIGHT ON TUBE TYP
Westinghouse Electric Corporation
TITLE 3,000 HP, 6-POLE MOTOR
MANIFOLD DETAIL
1:4
B522D39


3,000 H.P., 6-POLE MOTOR
MANIFOLD DETAIL
8522D40
SECTION A-A
SCALE 1:1
SECTION C-C
DETAIL - B
SCALE 1:2
SEE DETAIL - B
.328 DIA THRU ITEMS - 03, 04, 05, & 06
& 1 WALL OF ITEM - 01
(.126 - 27 NPT (SEE SECTION A-A)
ON A 42.250 DIA. BC.
22 - HOLES THIS SIDE &
2 - HOLES FAR SIDE
(24 - HOLES TOTAL)
SPACED AS SHOWN
NEAR SIDE & FAR SIDE
1.00 APPROX STRAIGHT ON TUBE TYP
A - WILLIAMS & CO. INC. PGH., PA.
B - MAY BE CUT FROM ONE ROLLED & MACHINED PIECE.
C - MUELLER BRASS CO. PORT HURON, MICH. 48060.
NOTES:
1 - CLEAN INSIDE MANIFOLD PER DRAWING 1697864 & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 P.S.I. FOR 30 MINUTES.
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
(c) HELIUM LEAK TEST PER ASTM E-499 METHOD A AT 10 PSIG.
MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD 1×10⁻⁶ CM³/S
(d) SEAL ALL OPENINGS.
Westinghouse Electric Corporation
3,000 H.P., 6-POLE MOTOR
MANIFOLD DETAIL
8522D40


DETAIL-B
SCALE 1:2
SEE DETAIL-B
SECTION C-C
SECTION A-A
SCALE 1:1
A - WILLIAMS & CO. INC. PGH., PA.
B - MAY BE CUT FROM ONE ROLLED & MACHINED PIECE.
C - MULLER BRASS CO. PORT HURON, MICH. 48060.
NOTES:
Westinghouse Electric Corporation
TITLE 5,000 H.R. 6-POLE MOTOR
MANIFOLD DETAIL
REV 1
8522D47


5,000 H.P. 6-POLE MOTOR
MANIFOLD DETAIL
852ZD48
DETAIL-B
SCALE 1:2
SEE DETAIL-B
SECTION C-C
SECTION A-A
SCALE 1:1
NEAR SIDE & FAR SIDE
A - WILLIAMS & CO. INC. PGH., PA.
B - MAY BE CUT FROM ONE ROLLED & MACHINED PIECE.
C - MULLER BRASS CO. PORT HURON, MICH 48060.
NOTES:
1- CLEAN INSIDE MANIFOLD PER DRAWING 1697B64 & TEST AS FOLLOWS:
(a) HYDROSTATIC TEST AT 100 P.S.I. FOR 30 MINUTES
(b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE
(c) HELIUM LEAK TEST PER ASTM E-499 METHOD A AT 10 PSIG
MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD 1x10⁻⁹ cm³/s
(d) SEAL ALL OPENINGS
Westinghouse Electric Corporation
5,000 H.P. 6-POLE MOTOR
MANIFOLD DETAIL
852ZD48



Item		Part Name		Description	Material Spec.		Group 1	Group 2			
01		CAP		.50 Lg. of 1.000 x 2.300 RECT CU BAR	6307-0201	ASTM B-[illegible]	2	2			
02		BLOCK		3.75 Lg. of 1.000 x 2.300 RECT CU BAR	6307-0201	ASTM B-[illegible]	1	-			
03		BLOCK		3.75 Lg. of 1.000 x 2.300 RECT CU BAR	6307-0201	ASTM B-[illegible]	-	1			
04		SOFT SOLDER		60% TIN 40% LEAD	P051763AG						
05		SOLDERING FLUX		ALCOHOL & ROSIN	6553301AA						

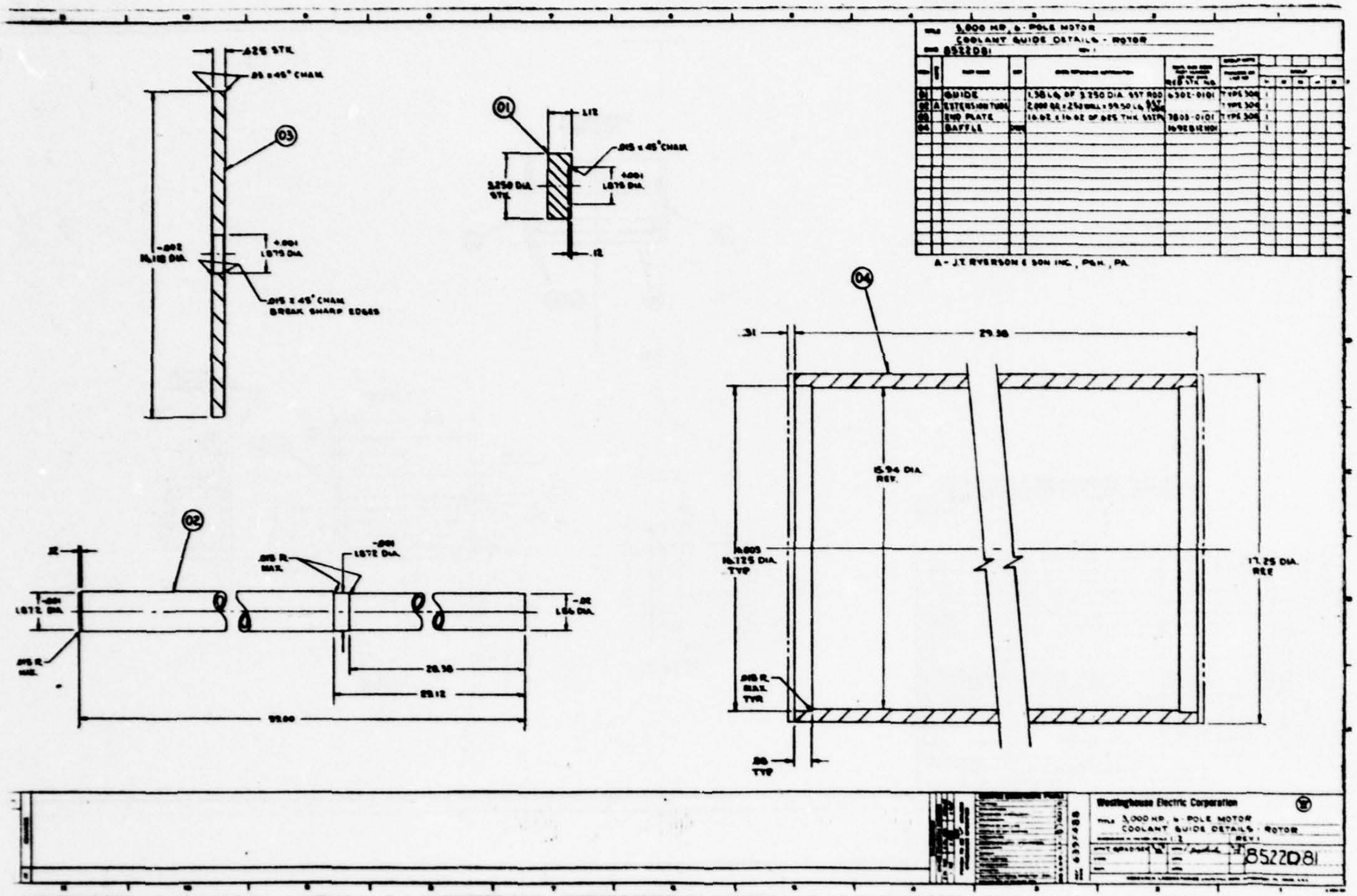
NOTES:

1. POCKET DIMENSIONS ARE ONLY FOR A DEPTH OF .16 [illegible] OF [illegible]. THE REMAINING DEPTH MAY HAVE A MORE LIBERAL TOLERANCE OF ±.030

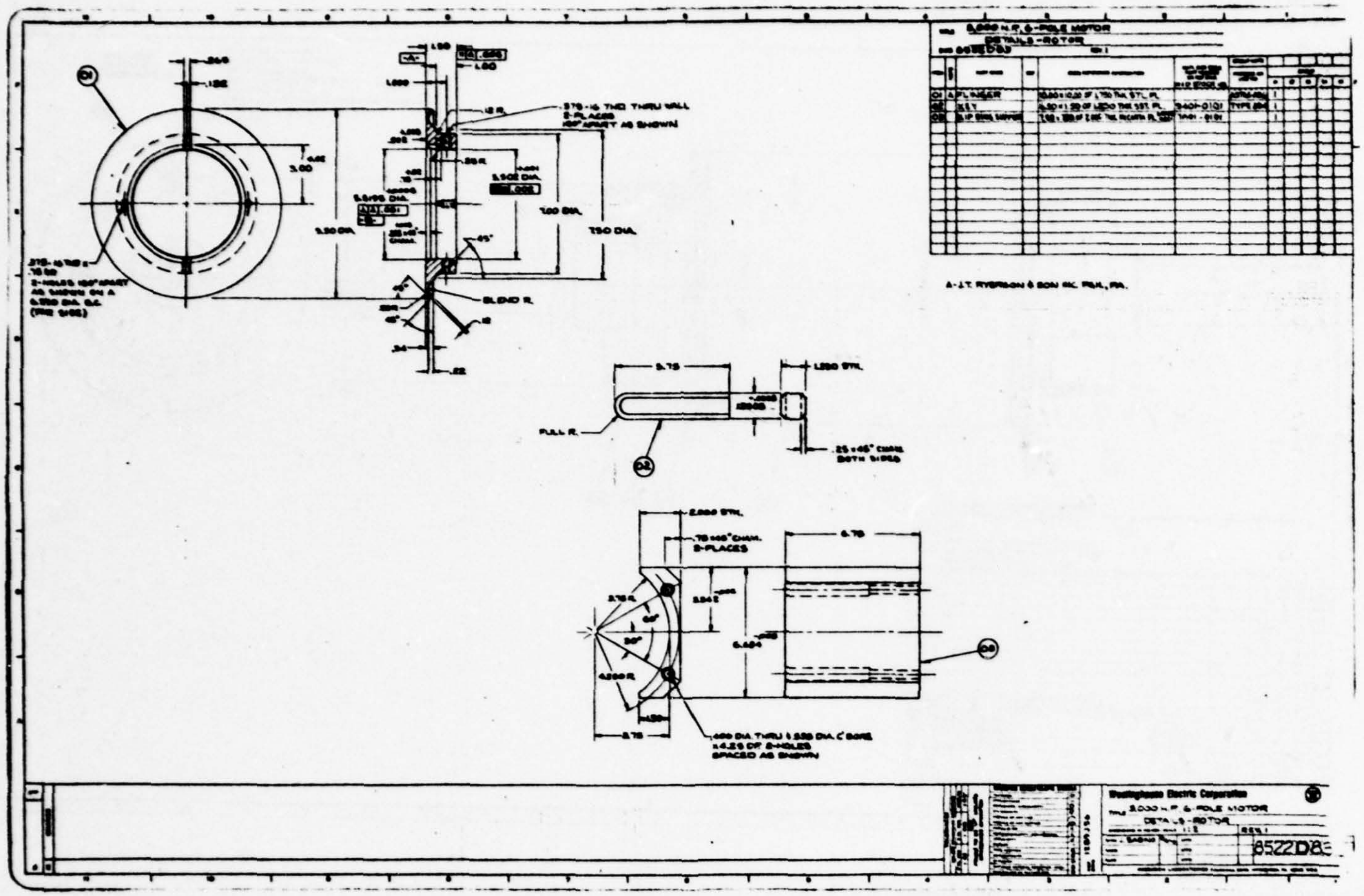
Westinghouse Electric Corporation

TITLE 3,000 H.P., 6 POLE MOTOR HOMOPOLAR [illegible] FIELD COIL STATOR

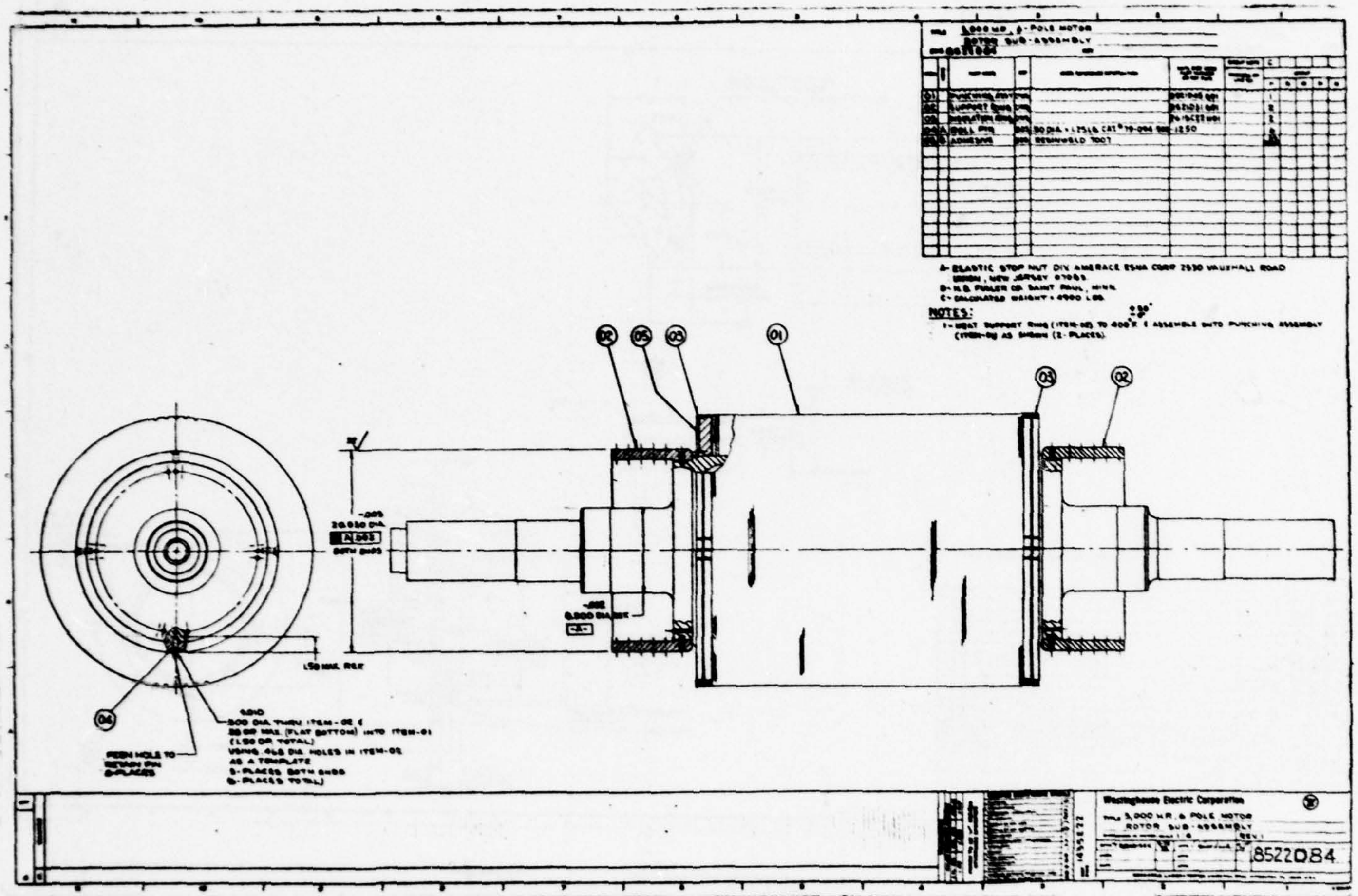
8522D51



3,000 HP, 6-POLE MOTOR
COOLANT GUIDE DETAILS - ROTOR
8522D81
01 GUIDE 1.38 LG. OF 3.250 DIA. SST ROD 6302-0101 TYPE 304 1
02 A EXTENSION TUBE 2.000 OD x .250 WALL x 59.50 LG. SST. TUBE TYPE 304 1
03 END PLATE 16.02 x 16.02 OF .025 THK. SSTP. 7803-0101 TYPE 304 1
04 BAFFLE 1 1
A - J.T. RYERSON & SON INC., PGH., PA.
.625 STK.
.06 x 45° CHAM.
.015 x 45° CHAM.
BREAK SHARP EDGES
1.875 DIA.
3.250 DIA. STK.
1.12
.12
29.38
.31
15.94 DIA. REF.
17.25 DIA. REF.
TYP
28.38
29.12
59.00
1.872 DIA.
1.66 DIA.
Westinghouse Electric Corporation
3,000 HP, 6-POLE MOTOR
COOLANT GUIDE DETAILS - ROTOR
REV. 1
8522D81



2,000 H.P. 6-POLE MOTOR
DETAILS - ROTOR
FULL R.
BLEND R.
7.00 DIA.
7.50 DIA.
.25 x 45° CHAM. BOTH SIDES
2-PLACES
SPACED AS SHOWN
A - J.T. RYERSON & SON INC. PHIL., PA.
Westinghouse Electric Corporation
2,000 H.P. 6-POLE MOTOR
DETAILS - ROTOR
8522D83



A- ELASTIC STOP NUT DIV AMERACE ESNA CORP 2530 VAUXHALL ROAD UNION, NEW JERSEY 07083
C- CALCULATED WEIGHT 4900 LBS.
NOTES:
01
02
03
04
05
Westinghouse Electric Corporation
3,000 H.P. 6 POLE MOTOR
ROTOR SUB-ASSEMBLY
8522D84

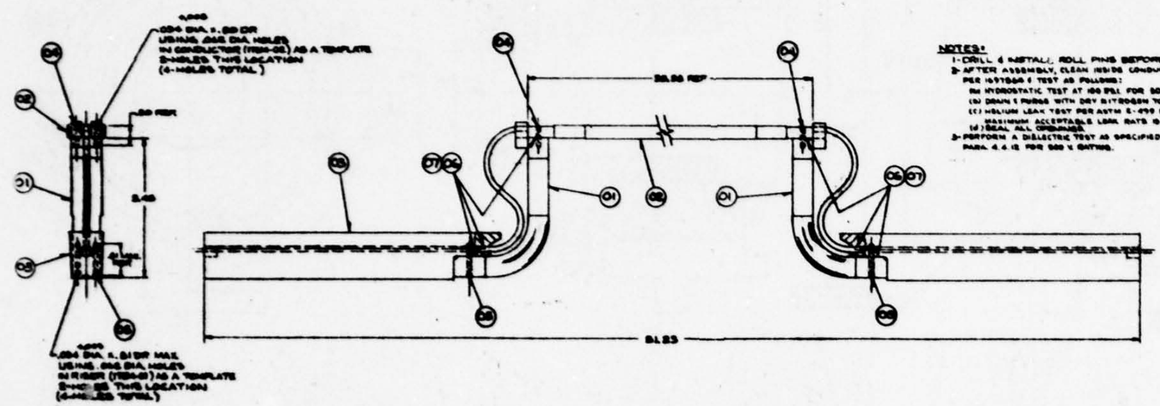
8,000 H.P. 6-POLE MOTOR
RISER ASSEMBLY-ROTOR
8522D89

Item		Part Name	Qty	Description	Part No.		Qty
01		RISER	[illegible]		[illegible]		2
02		CONDUCTOR	[illegible]		[illegible]		1
03		COMMUTATOR BAR	[illegible]		[illegible]		2
04	A	ROLL PIN	[illegible]	[illegible] DIA x .50 LG BR CU CAT NO.	97-[illegible]-[illegible]-0500		4
05	A	ROLL PIN	[illegible]	[illegible] DIA x .75 LG BR CU CAT NO.	97-[illegible]-[illegible]-0750		4
06		SOFT SOLDER		60% TIN, 40% LEAD	[illegible]		[illegible]
07		SOLDERING FLUX		ROSIN & ALCOHOL	[illegible]		[illegible]

A-ELASTIC STOP NUT DIV., AMERACE ESNA CORP. 2330 VAUXHALL ROAD UNION, N.J. 07083.

<u>NOTES:</u>

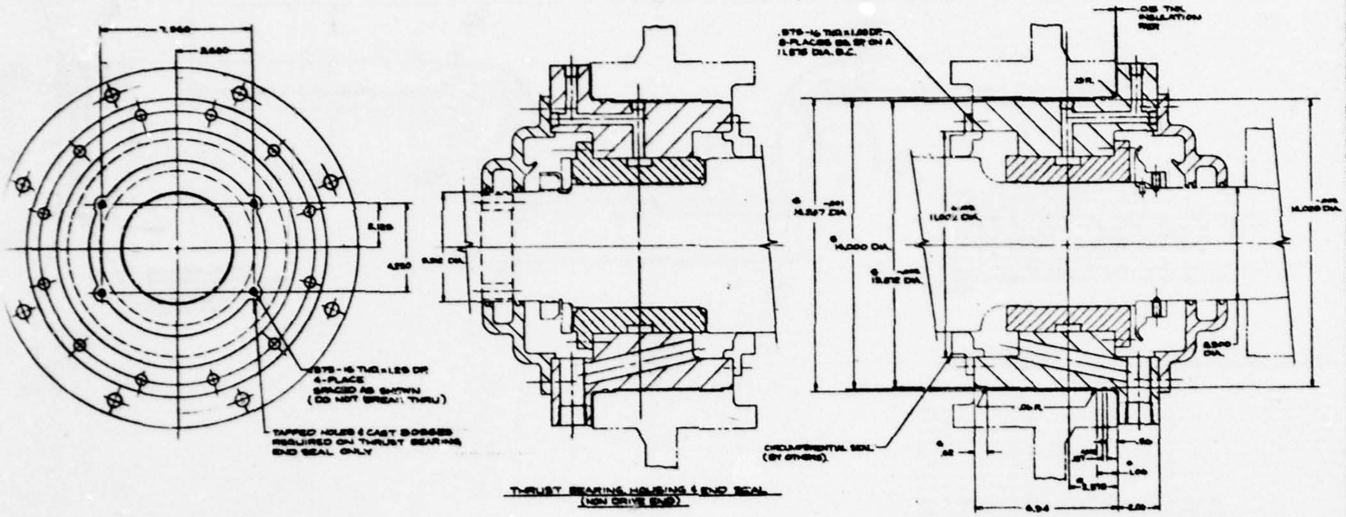
1- DRILL & INSTALL ROLL PINS BEFORE SOLDERING.
2- AFTER ASSEMBLY, CLEAN INSIDE CONDUCTOR TUBE & COMMUTATOR BAR PER [illegible] & TEST AS FOLLOWS:
   (a) HYDROSTATIC TEST AT 100 PSI FOR 30 MINUTES.
   (b) DRAIN & PURGE WITH DRY NITROGEN TO REMOVE MOISTURE.
   (c) HELIUM LEAK TEST PER ASTM E-499 METHOD "A" AT 10 P.S.I.G. MAXIMUM ACCEPTABLE LEAK RATE IS STANDARD 1×10^{-6} CM³/S
   (d) SEAL ALL OPENINGS.
3- PERFORM A DIELECTRIC TEST AS SPECIFIED IN MIL-G-[illegible] (SHIPS) PARA. 4.4.12 FOR 500 V RATING.



Westinghouse Electric Corporation

TITLE 8,000 H.P., 6-POLE MOTOR
RISER ASSEMBLY-ROTOR

8522D89



NOTES:
1- DIMENSIONS MARKED ⊕ ARE WITH .015 THK PLASMA SPRAY ALUMINUM OXIDE Al_2O_3. APPLICATION & GRINDING TO BE FURNISHED BY WESTINGHOUSE.
2- BEARINGS, HOUSING & END SEALS ARE THE SAME AS WAUKESHA BRG. CORP DRAWING D-075-000-91 EXCEPT AS NOTED.
3- LOCKING OF INTERNAL BOLTS TO BE SPECIFIED BY WAUKESHA BRG. CORP.

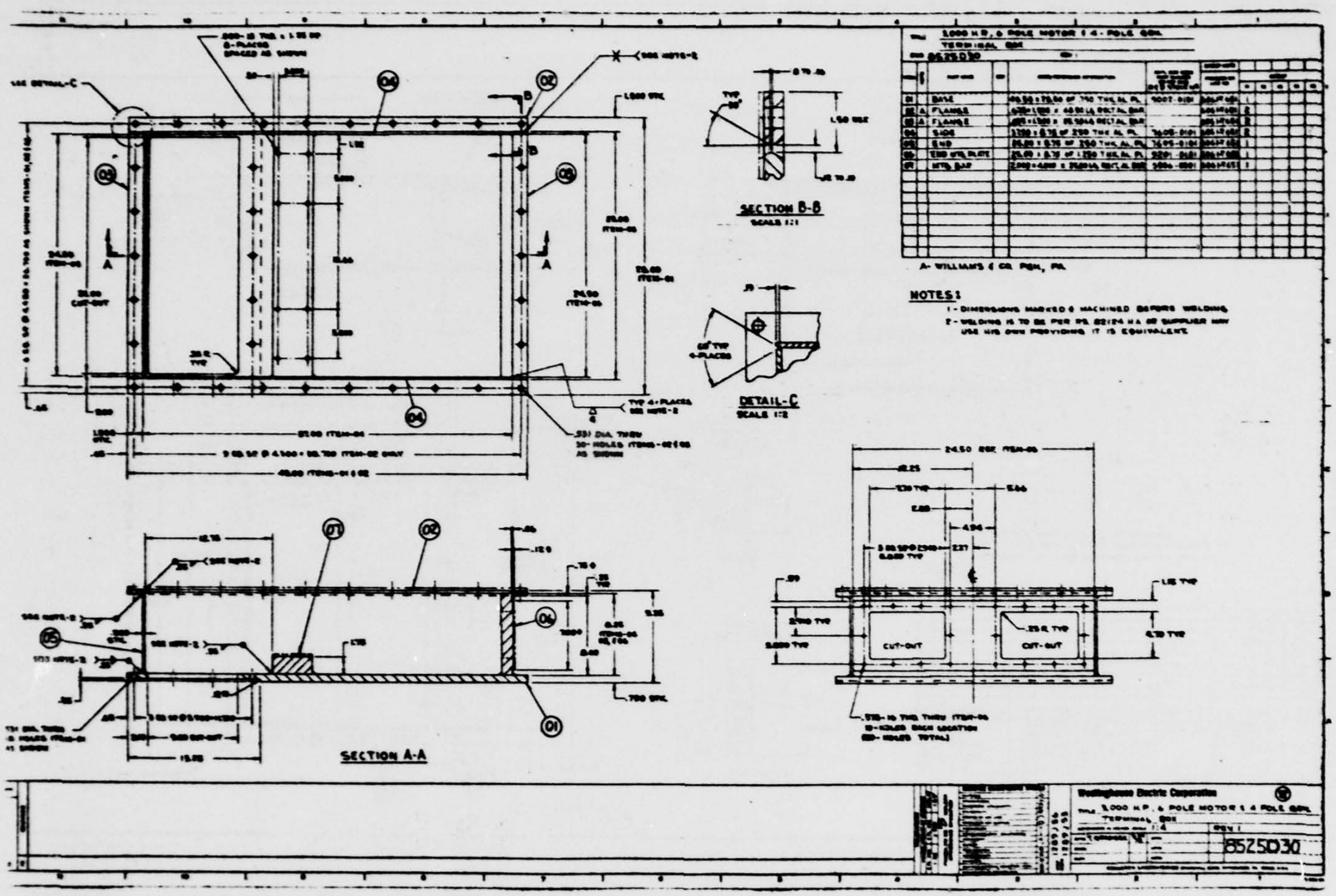
Westinghouse Electric Corporation

TITLE 3,000 H.P., 6-POLE MOTOR

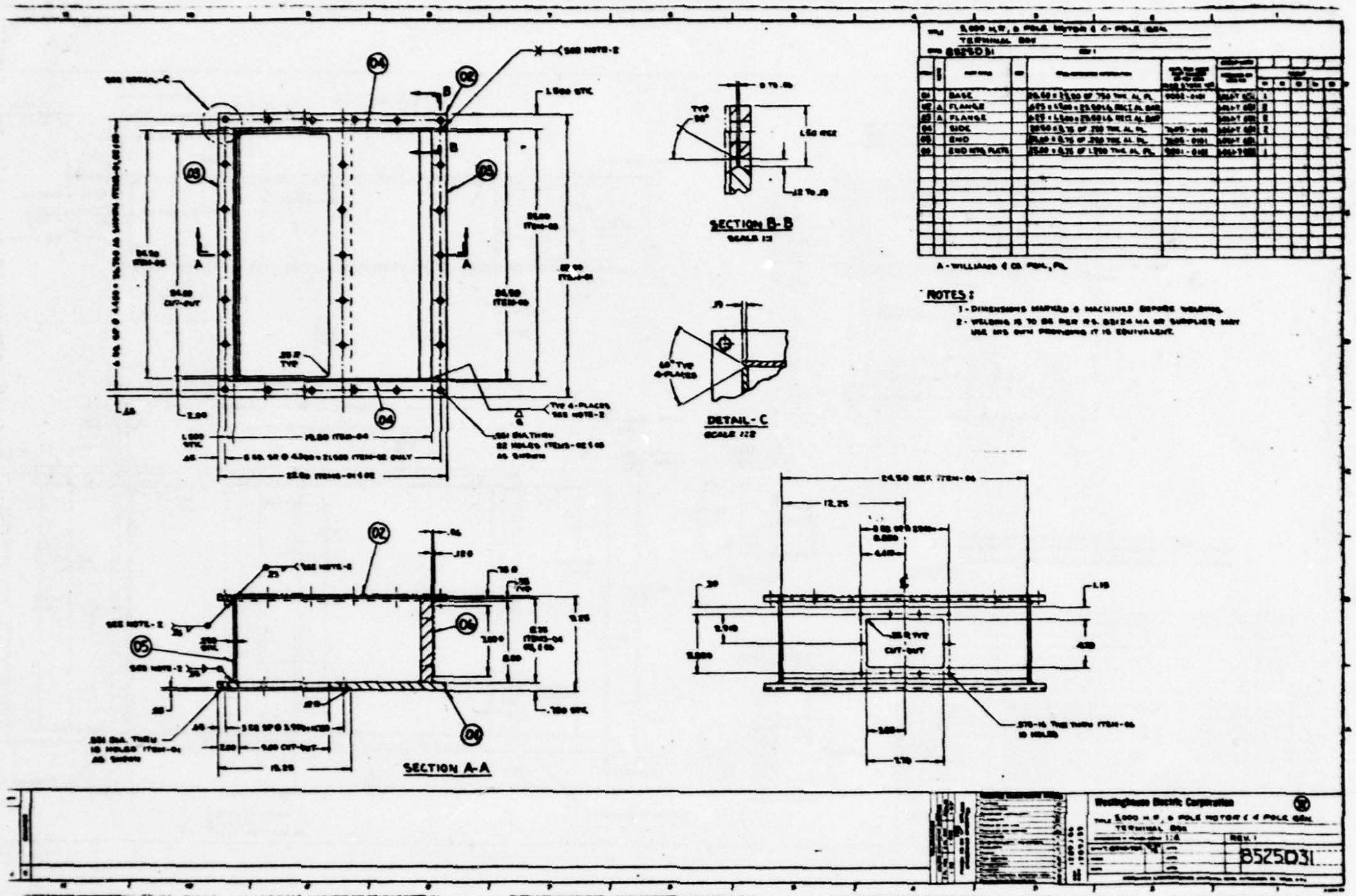
WAUKESHA D-075-000-91

REV. 1

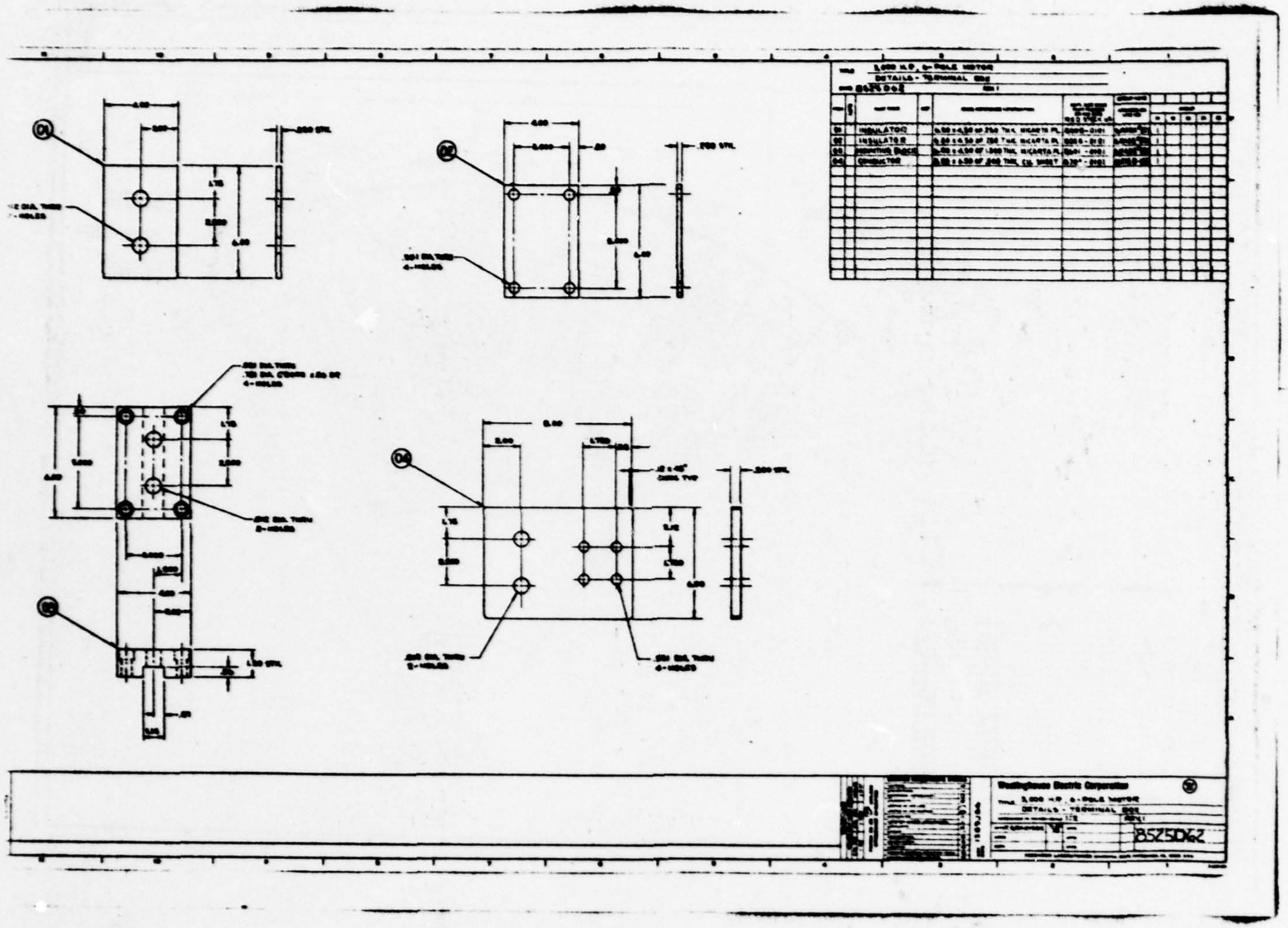
8525D27

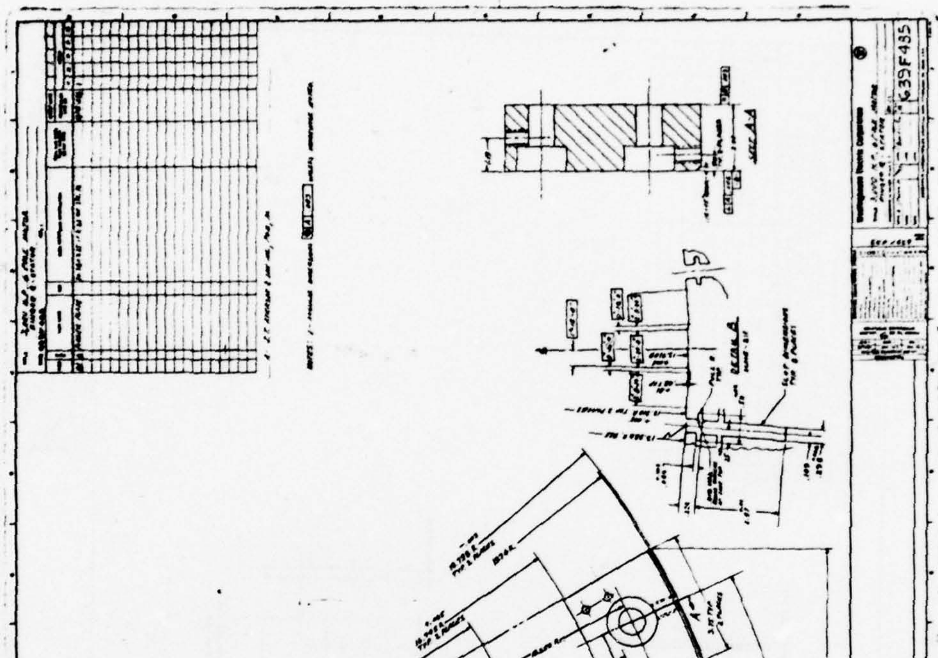


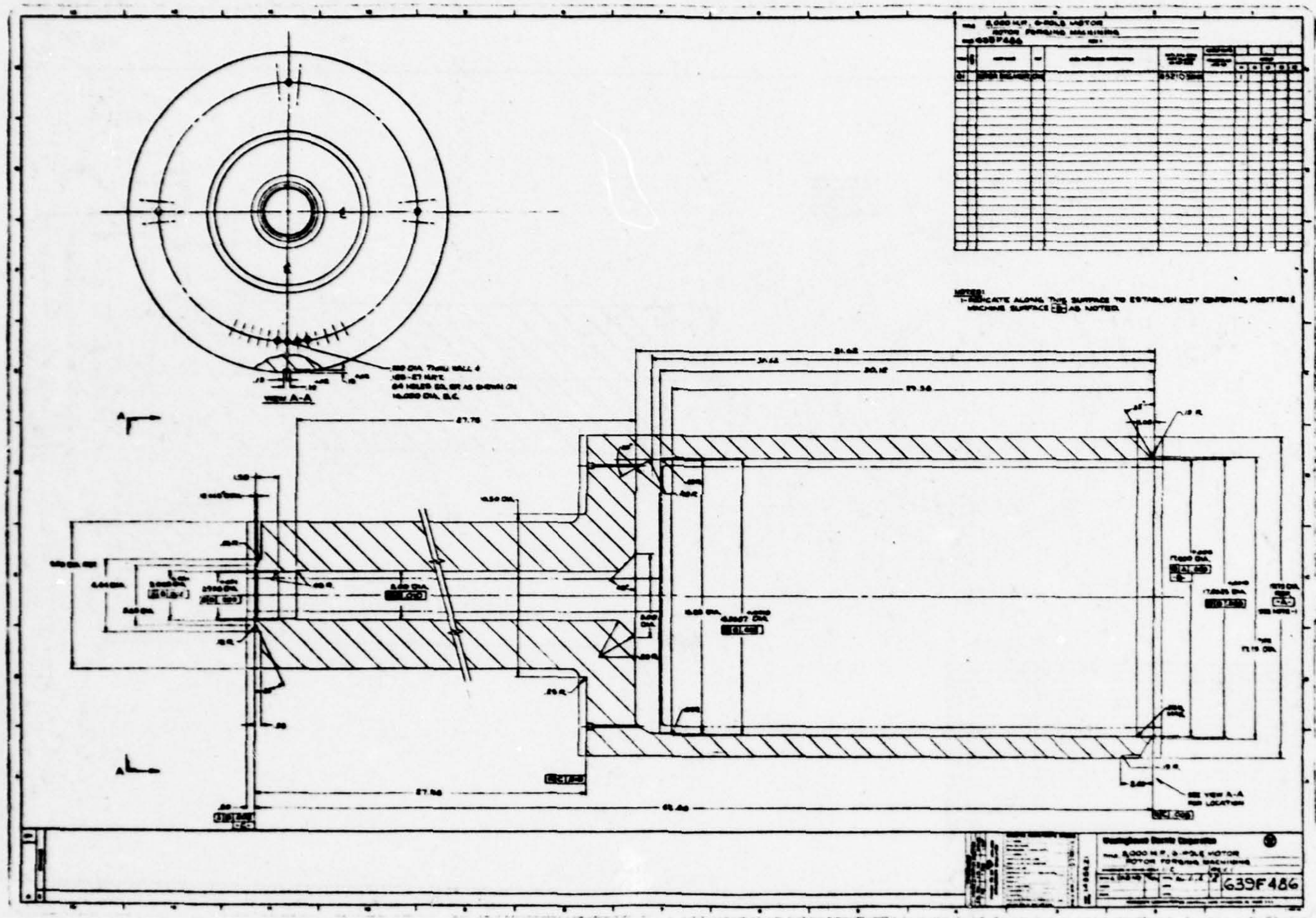
SECTION B-B
DETAIL-C
SECTION A-A
CUT-OUT
A- WILLIAMS & CO. PGH, PA.
NOTES:
1 - DIMENSIONS MARKED & MACHINED BEFORE WELDING
2 - WELDING IS TO BE PER PS 82124 HA OR SUPPLIER MAY USE HIS OWN PROVIDING IT IS EQUIVALENT
Westinghouse Electric Corporation
TITLE 2,000 H.P., 6 POLE MOTOR & 4 POLE GEN. TERMINAL BOX
8525030

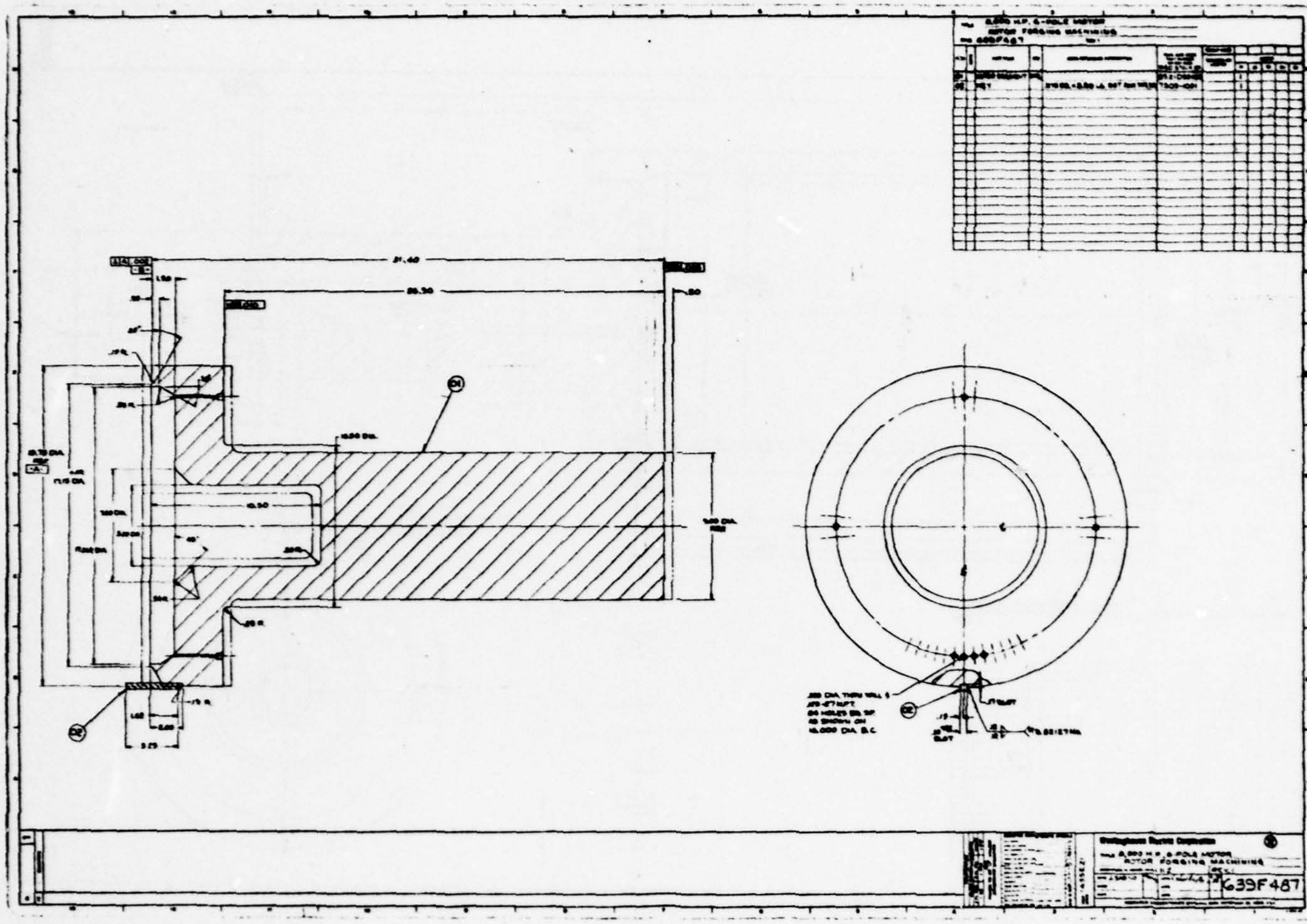


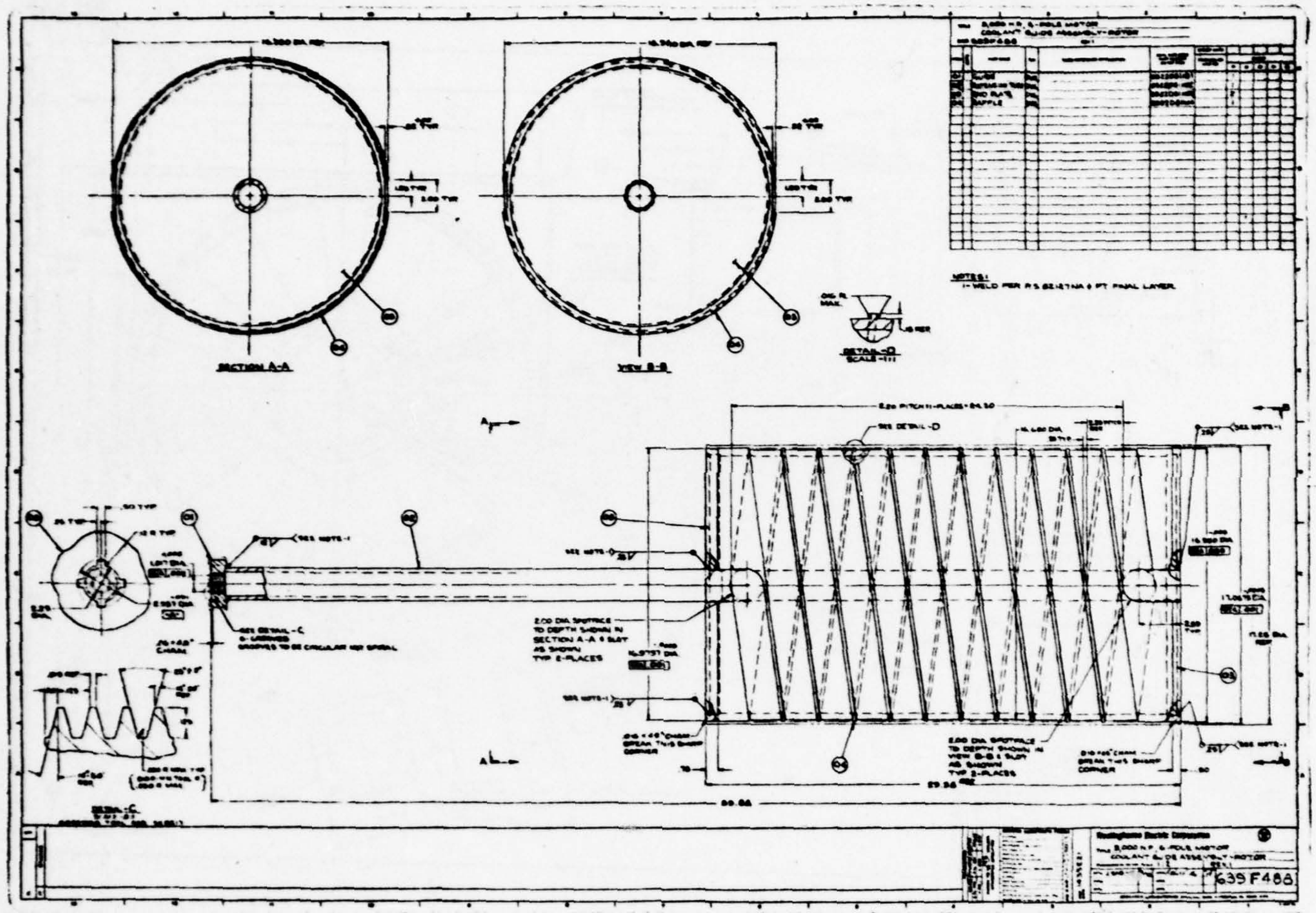
5,000 H.P., 6 POLE MOTOR & 4-POLE GEN.
TERMINAL BOX
B525D31
BASE
FLANGE
FLANGE
SIDE
END
END MTG. PLATE
A - WILLIAMS & CO. PGH., PA.
NOTES:
1 - DIMENSIONS MARKED ◊ MACHINED BEFORE WELDING.
2 - WELDING IS TO BE PER P.S. 83124 HA OR SUPPLIER MAY USE HIS OWN PROVIDING IT IS EQUIVALENT.
SECTION B-B
DETAIL - C
SECTION A-A
CUT-OUT
SEE NOTE-2
Westinghouse Electric Corporation
5,000 H.P., 6 POLE MOTOR & 4 POLE GEN.
TERMINAL BOX
1:4
REV. 1
B525D31

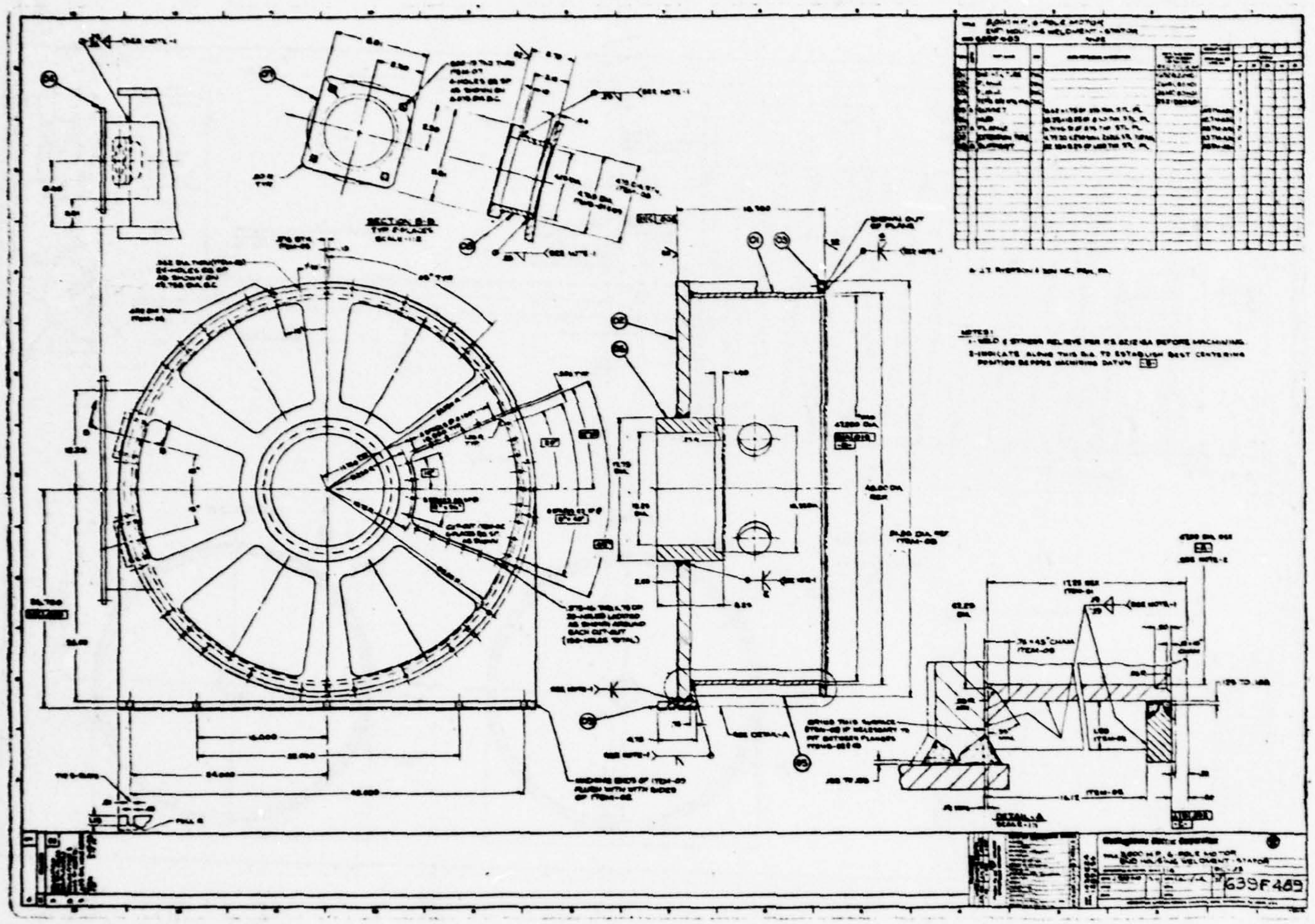

Westinghouse Electric Corporation
3,000 H.P., 6-POLE MOTOR
DETAILS - TERMINAL BOX
8525D62
INSULATOR
INSULATOR
CONDUCTOR


639F435


5,000 H.P., 6-POLE MOTOR
ROTOR FORGING MACHINING
NOTES:
1- INDICATE ALONG THIS SURFACE TO ESTABLISH BEST CENTERING POSITION & MACHINE SURFACE AS NOTED.
VIEW A-A
SEE VIEW A-A FOR LOCATION
5,000 H.P., 6-POLE MOTOR
ROTOR FORGING MACHINING
639F486


ROTOR FORGING MACHINING
639F487


SECTION A-A
VIEW B-B
DETAIL-D
DETAIL-C
639F488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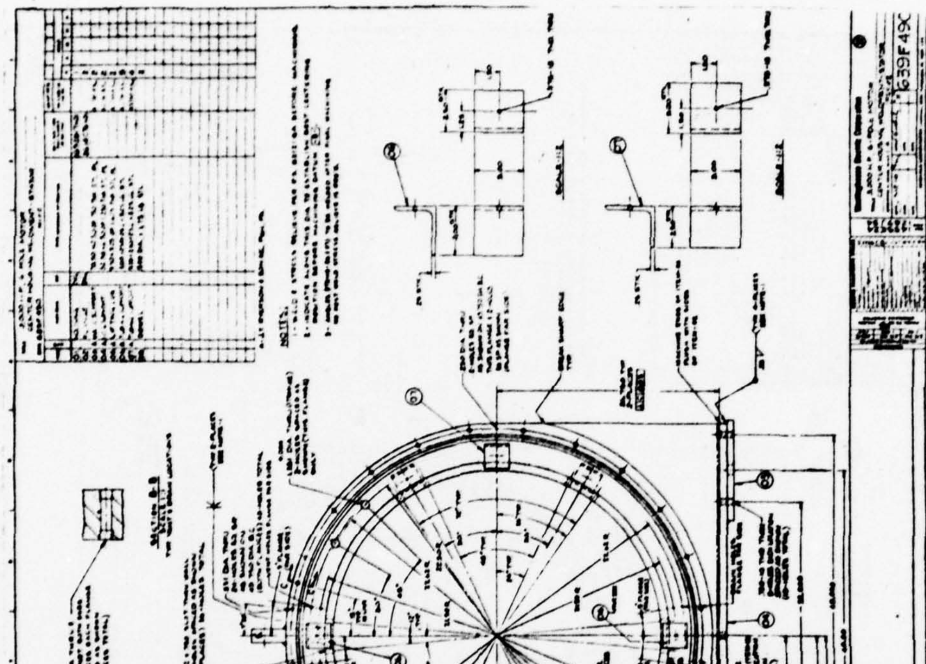
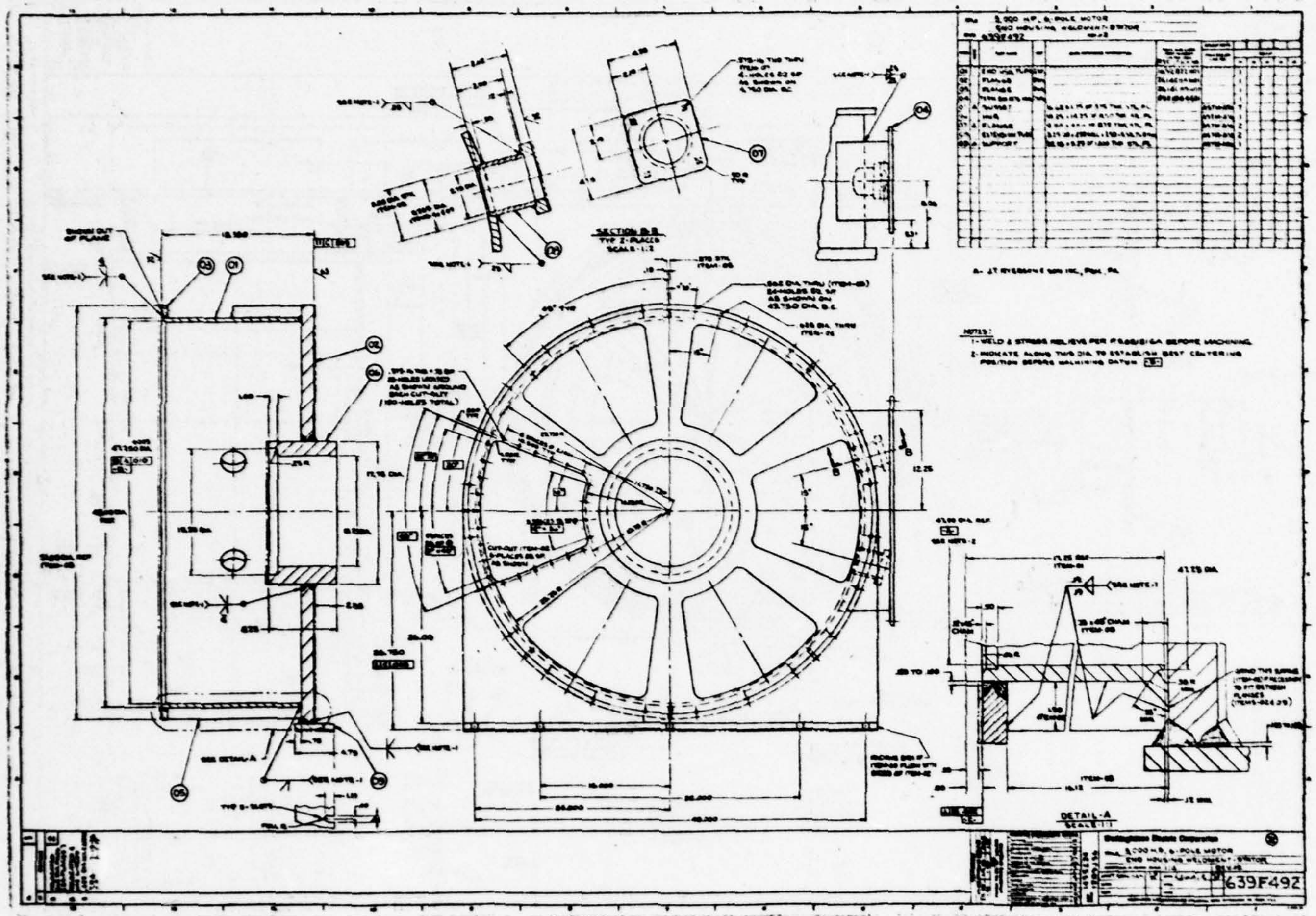
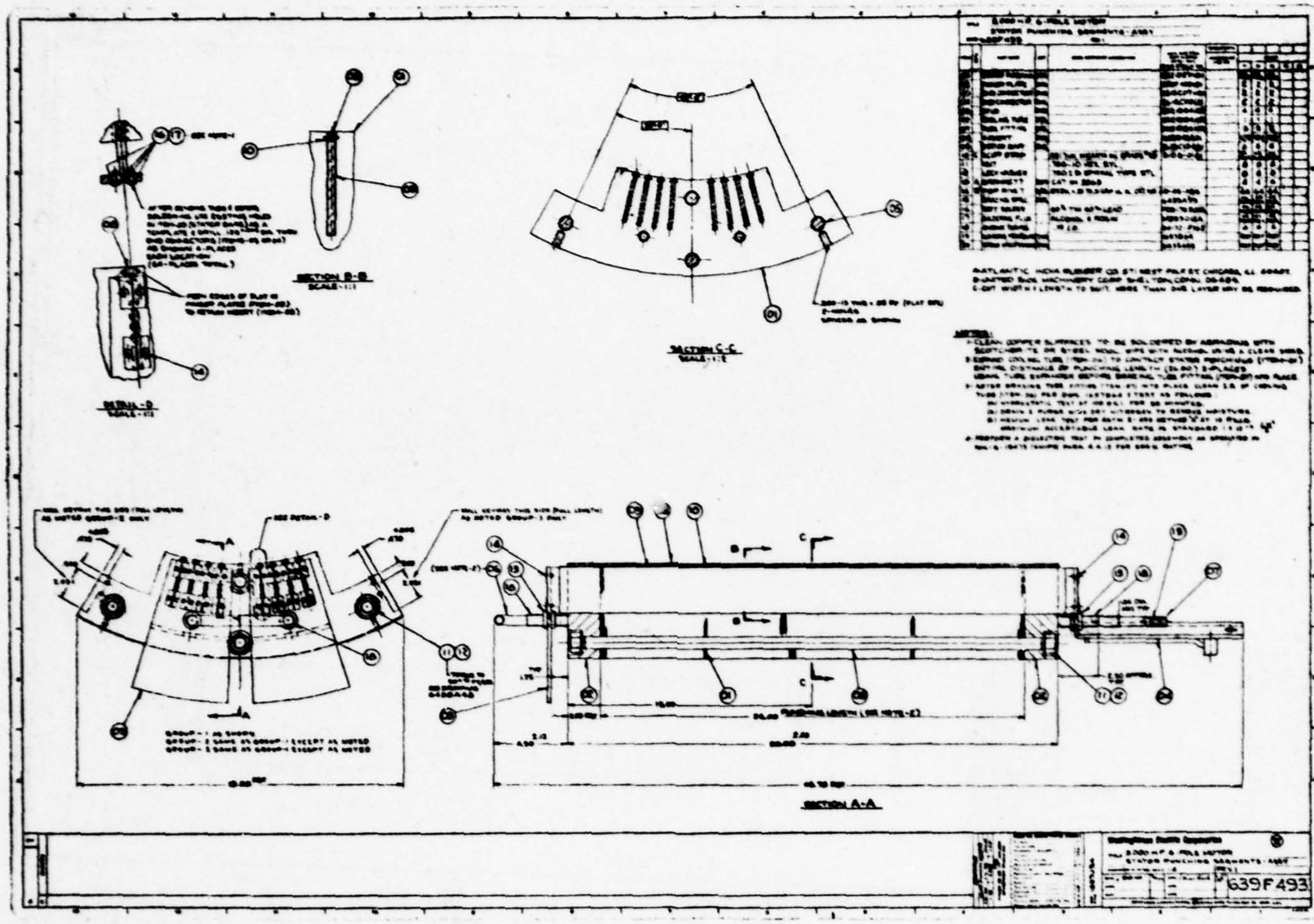
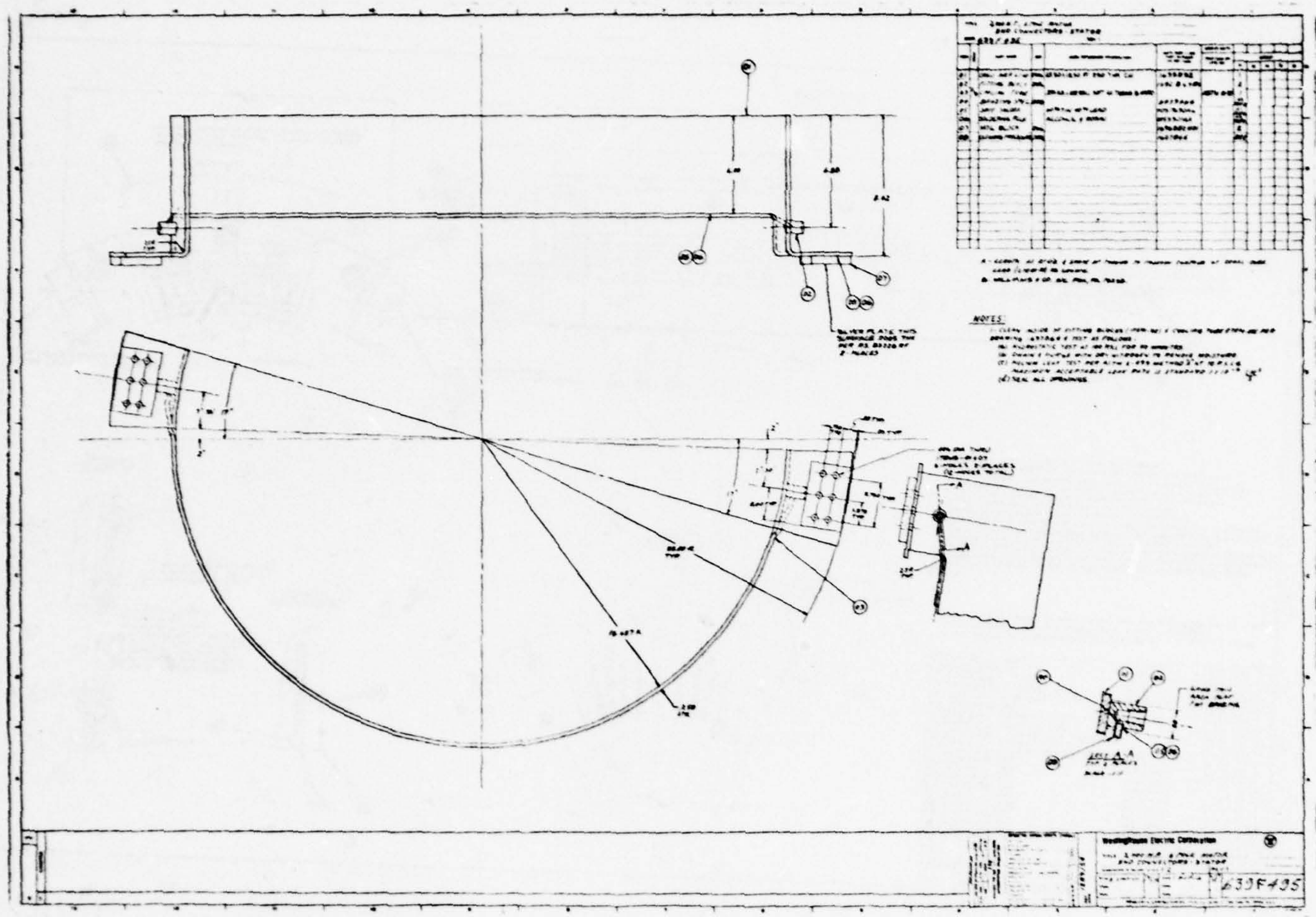
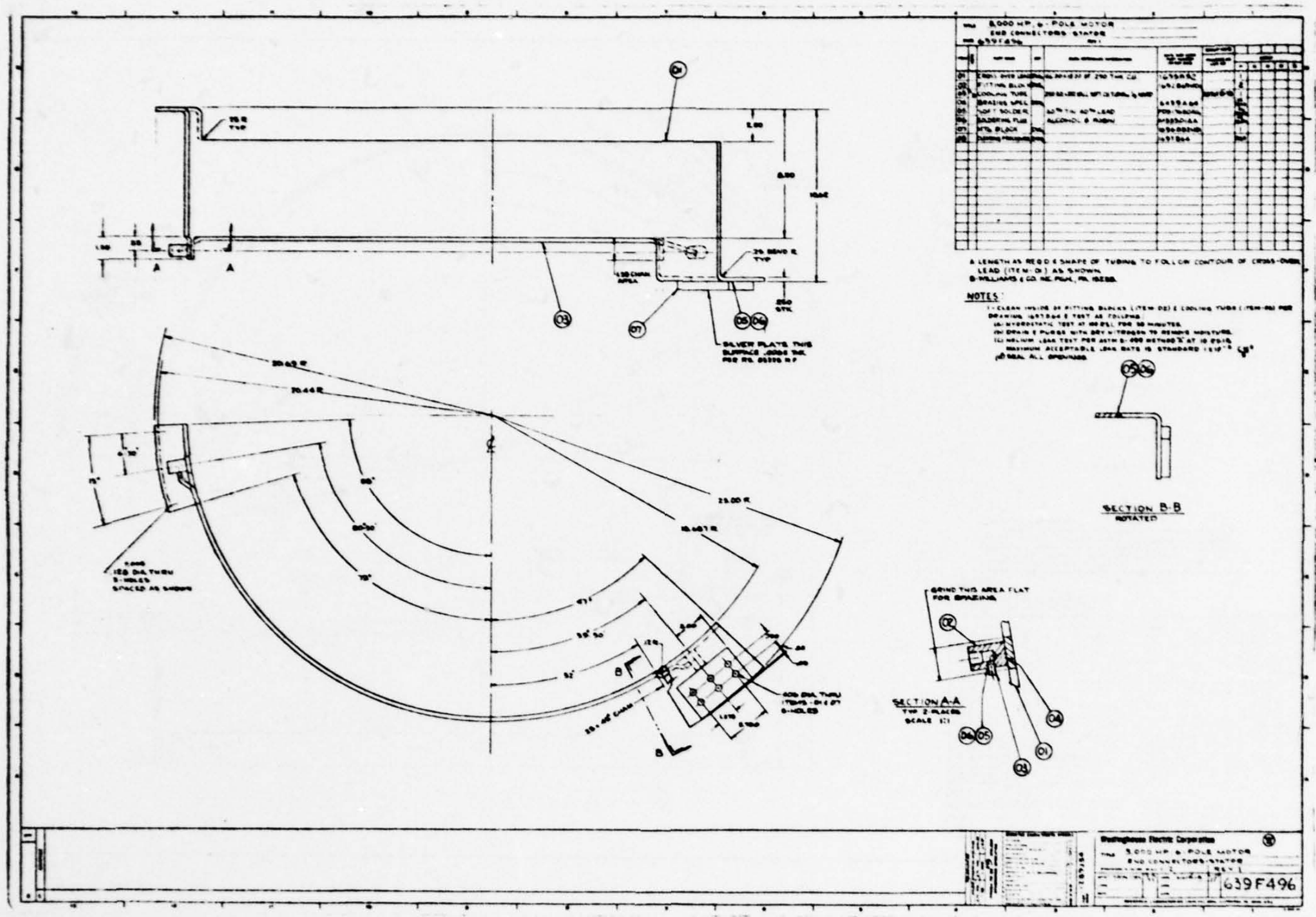


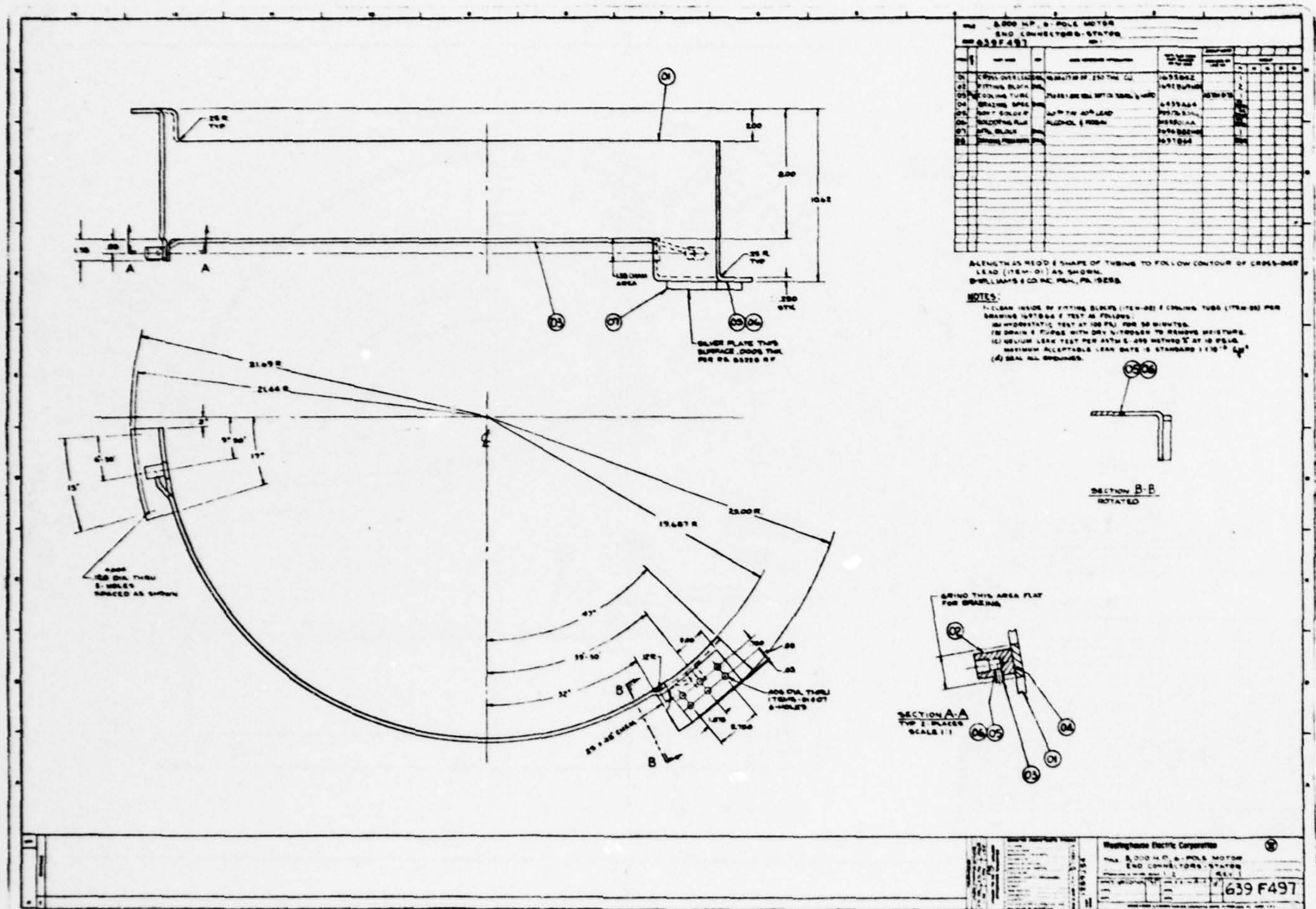

5,000 H.P., 6-POLE MOTOR
END HOUSING WELDMENT-STATOR
SECTION B-B
NOTES:
1- WELD & STRESS RELIEVE PER ... BEFORE MACHINING.
2- INDICATE ALONG THIS DIA. TO ESTABLISH BEST CENTERING POSITION BEFORE MACHINING DATUM
DETAIL-A
639F492


SECTION B-B
SECTION C-C
SECTION A-A
639F493

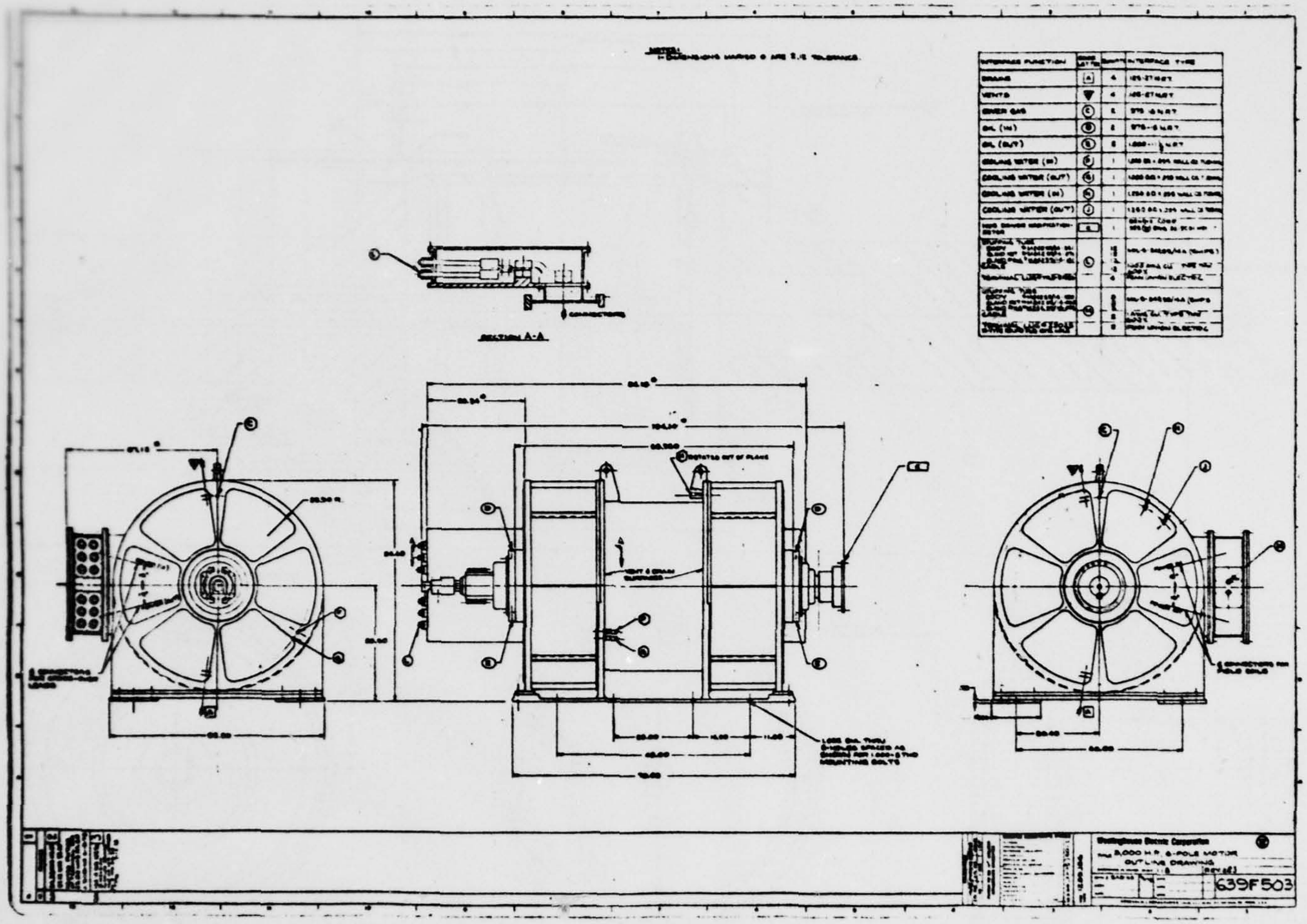

Westinghouse Electric Corporation
NOTES:

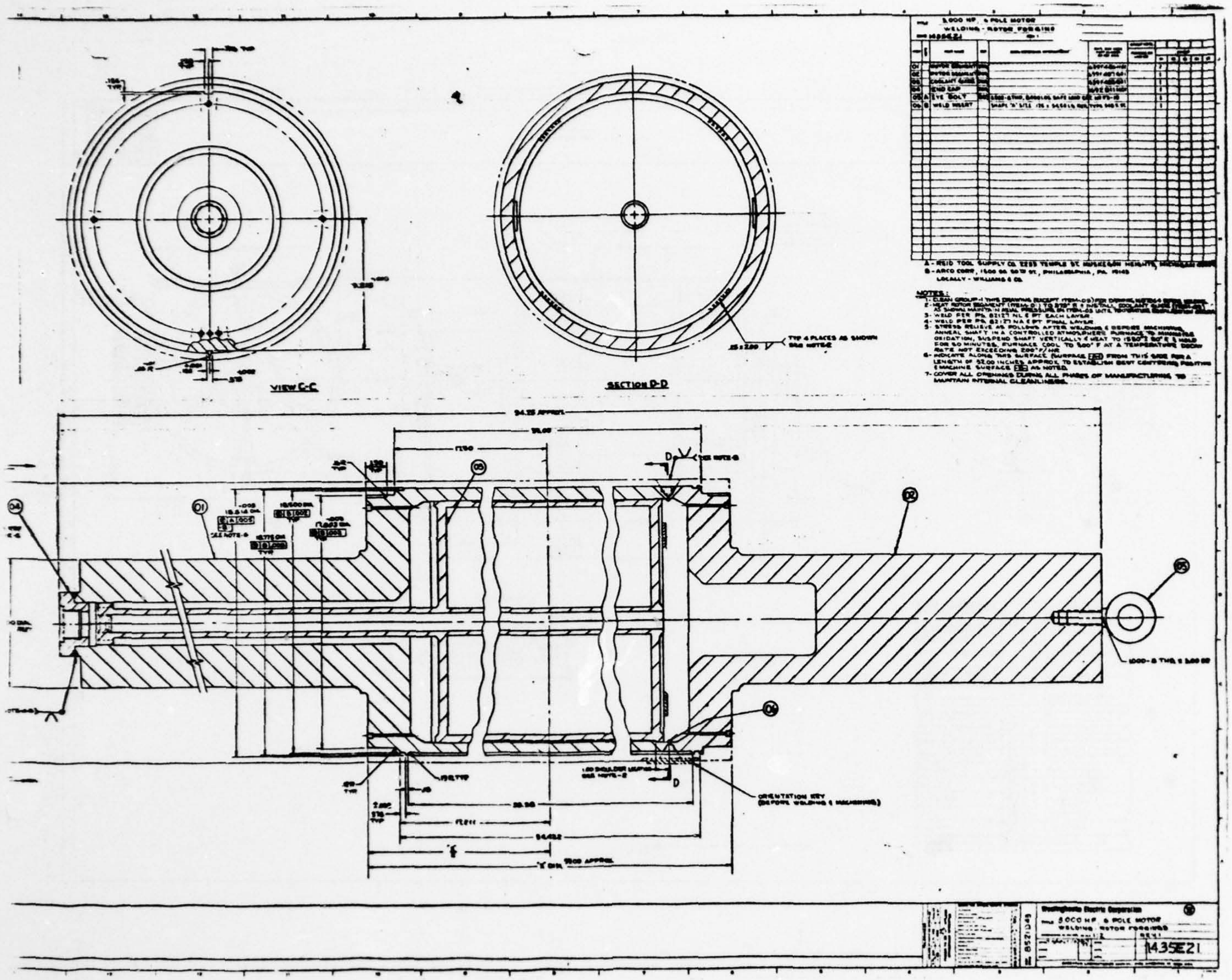


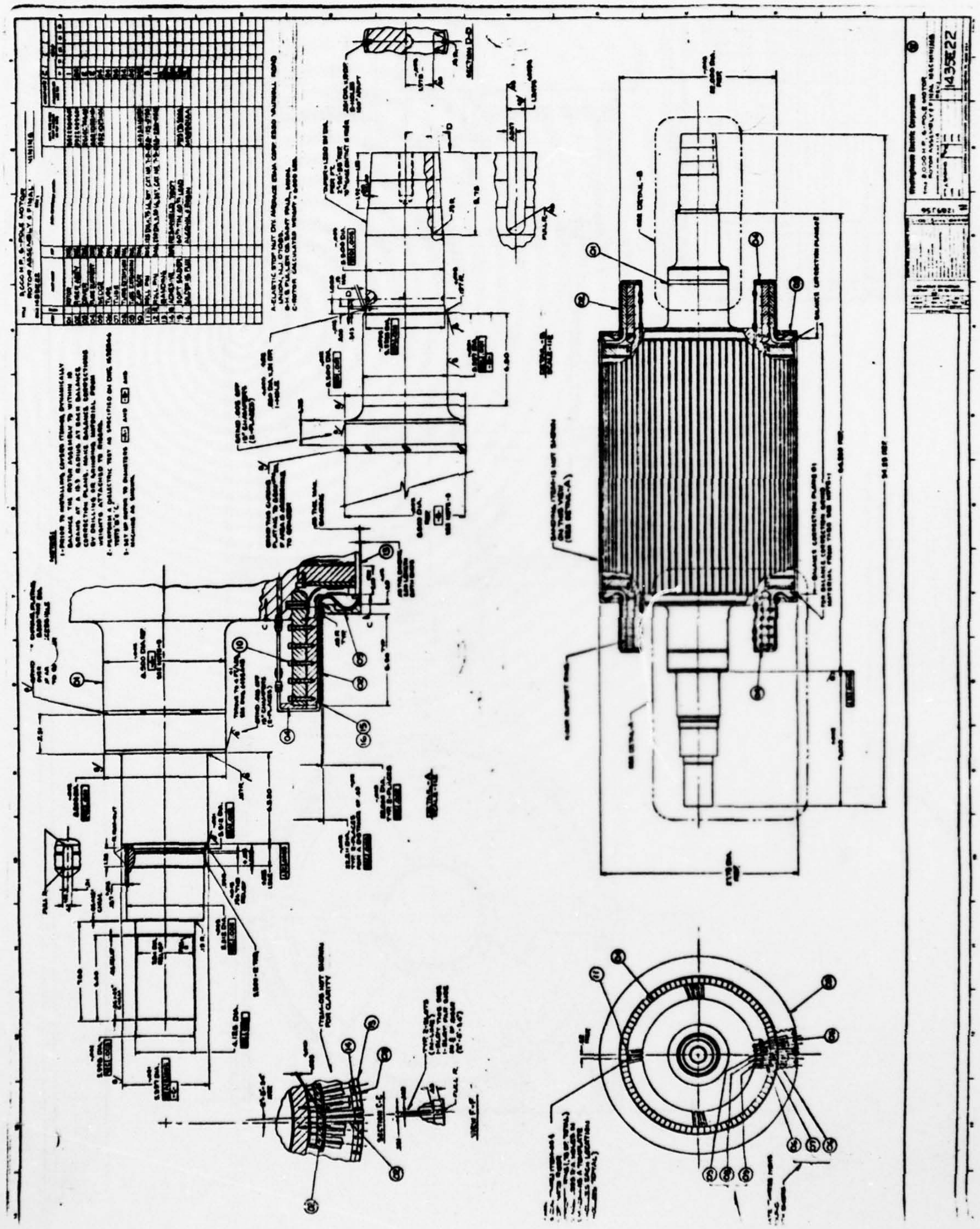
5,000 HP, 6-POLE MOTOR
END CONNECTORS-STATOR
A LENGTH AS REQ'D & SHAPE OF TUBING TO FOLLOW CONTOUR OF CROSS-OVER LEAD (ITEM-01) AS SHOWN.
NOTES:
SECTION B-B
ROTATED
SECTION A-A
GRIND THIS AREA FLAT FOR BRAZING
SILVER PLATE THIS SURFACE
23.00 R
Westinghouse Electric Corporation
639F496

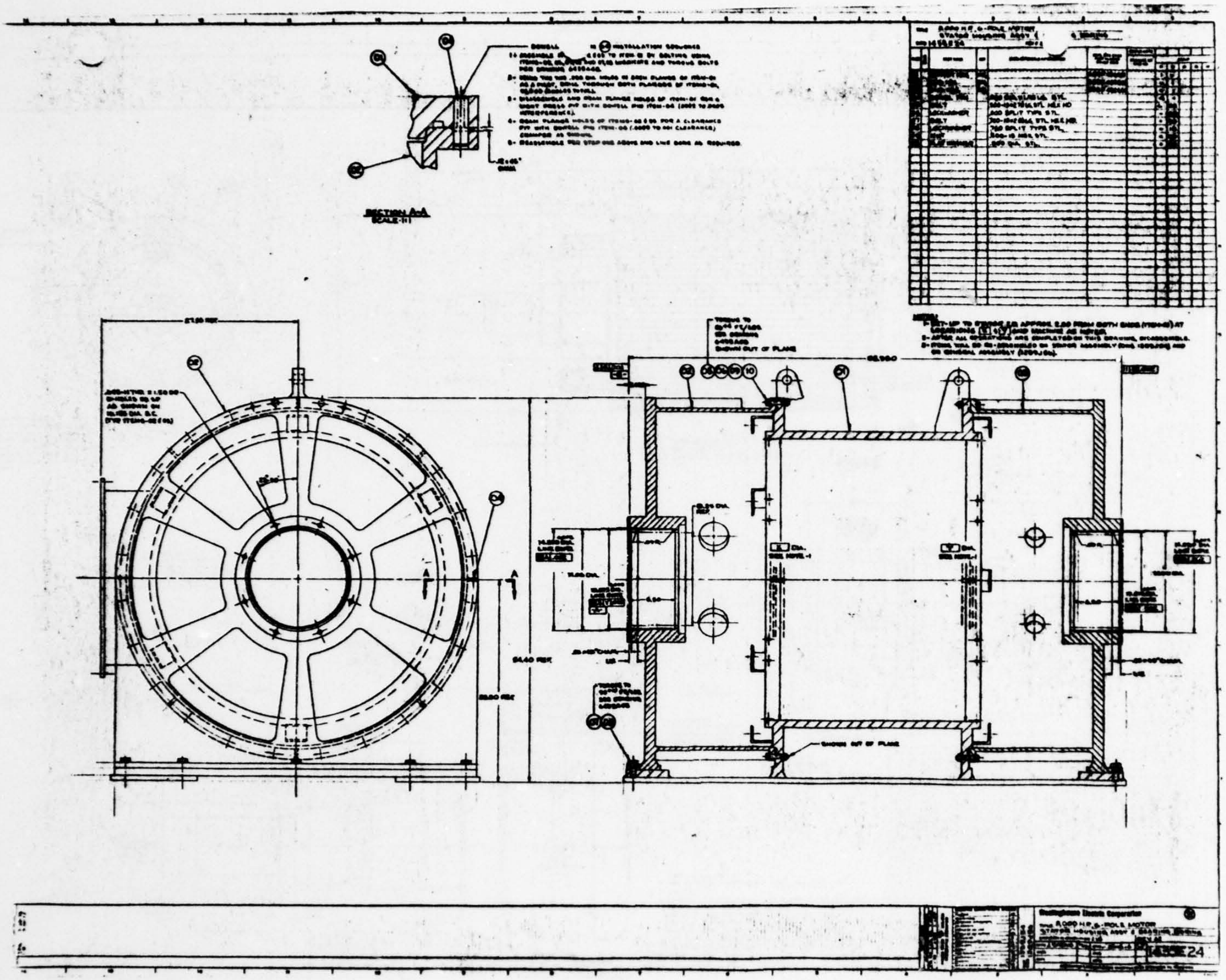


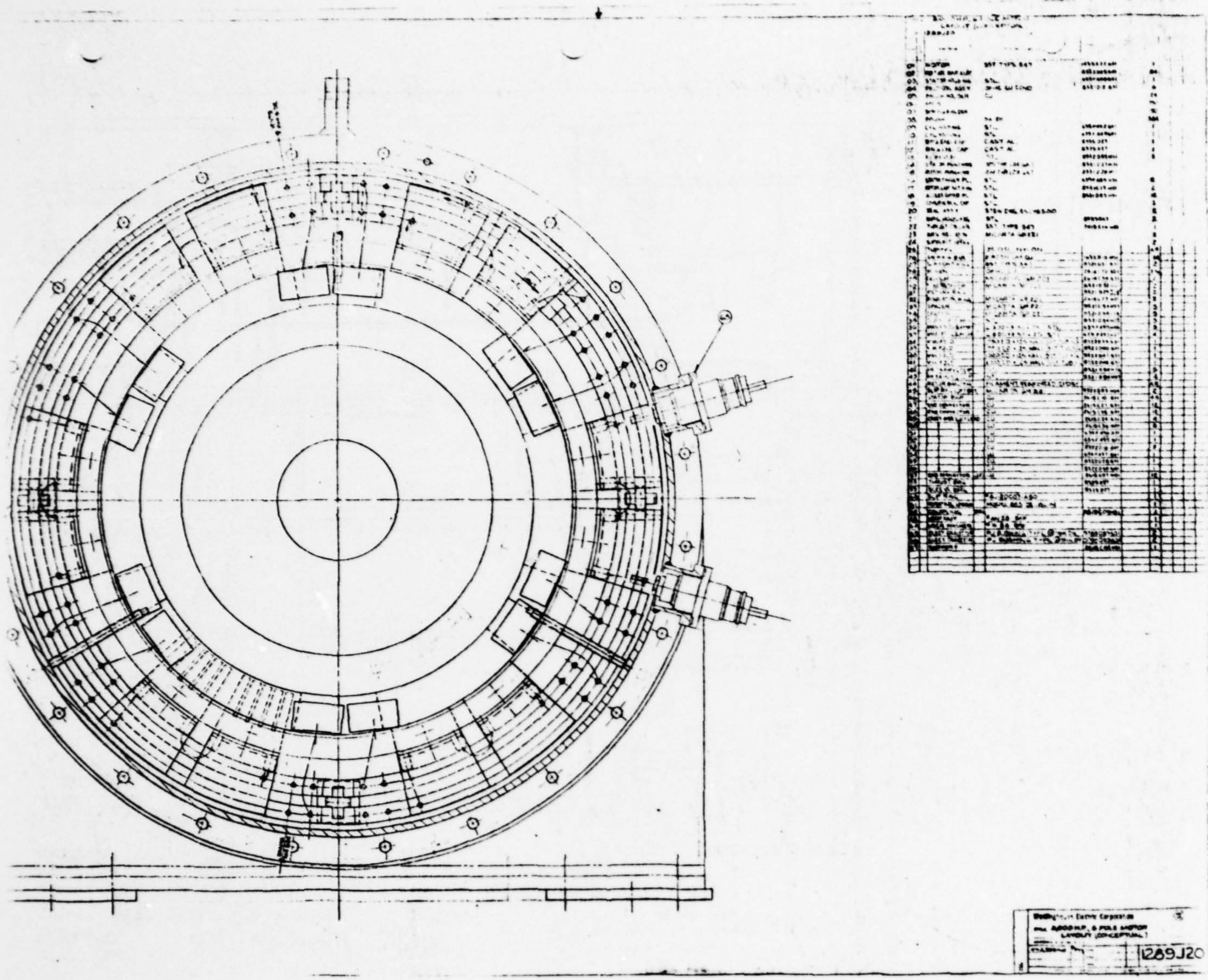
Westinghouse Electric Corporation
TITLE 5,000 H.P., 6-POLE MOTOR
END CONNECTORS-STATOR
639 F497
NOTES:
(d) SEAL ALL OPENINGS.
SECTION A-A
TYP 2 PLACES
SCALE 1:1
GRIND THIS AREA FLAT FOR BRAZING
SECTION B-B
ROTATED
SILVER PLATE THIS SURFACE .0005 THK.
21.69 R
21.44 R
22.00 R
19.687 R
10.62
8.00
2.00
.25 R TYP
.250 STK.
.406 DIA. THRU
.188 DIA. THRU
SPACED AS SHOWN

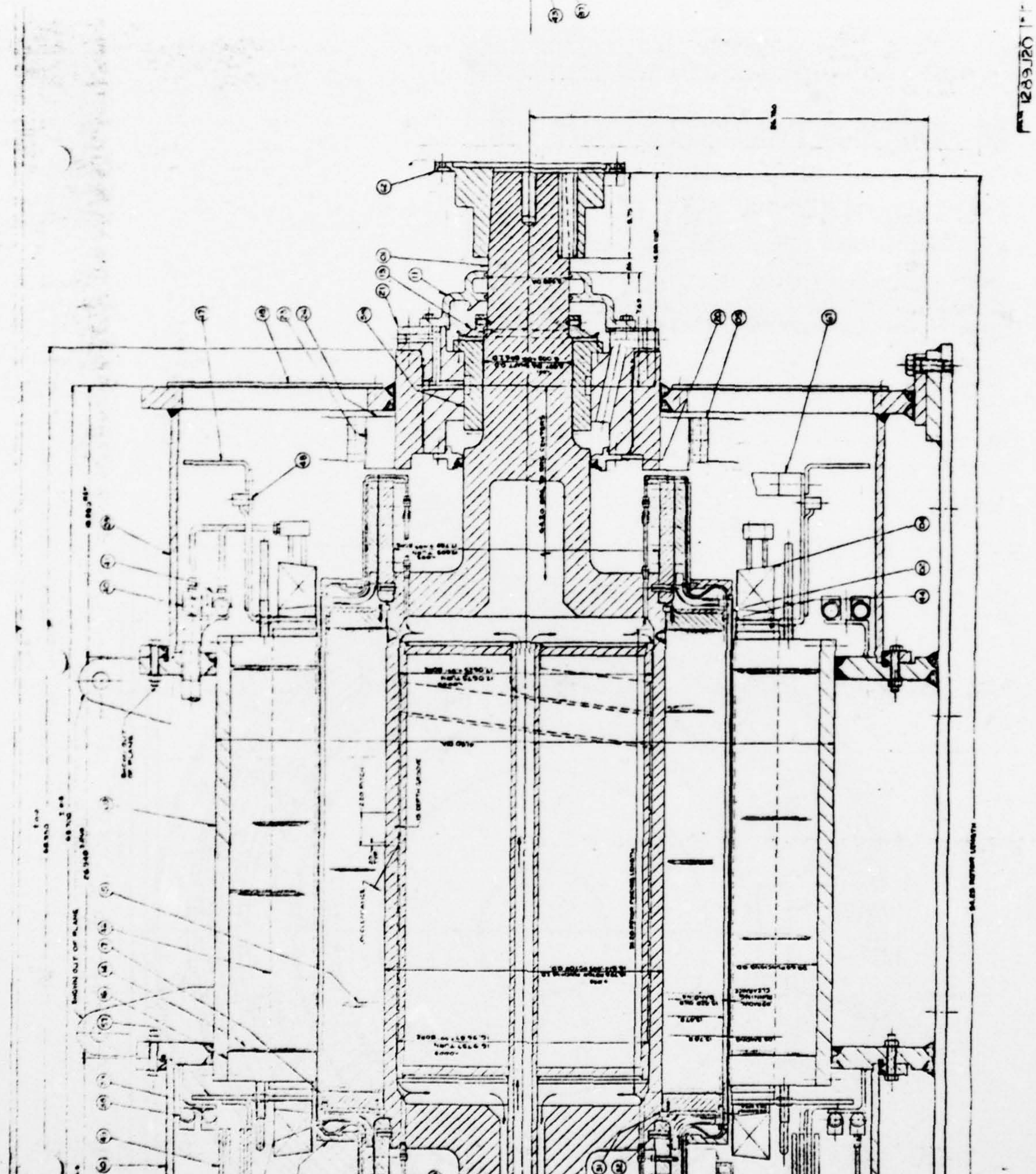

SECTION A-A
Westinghouse Electric Corporation
OUTLINE DRAWING
639F503

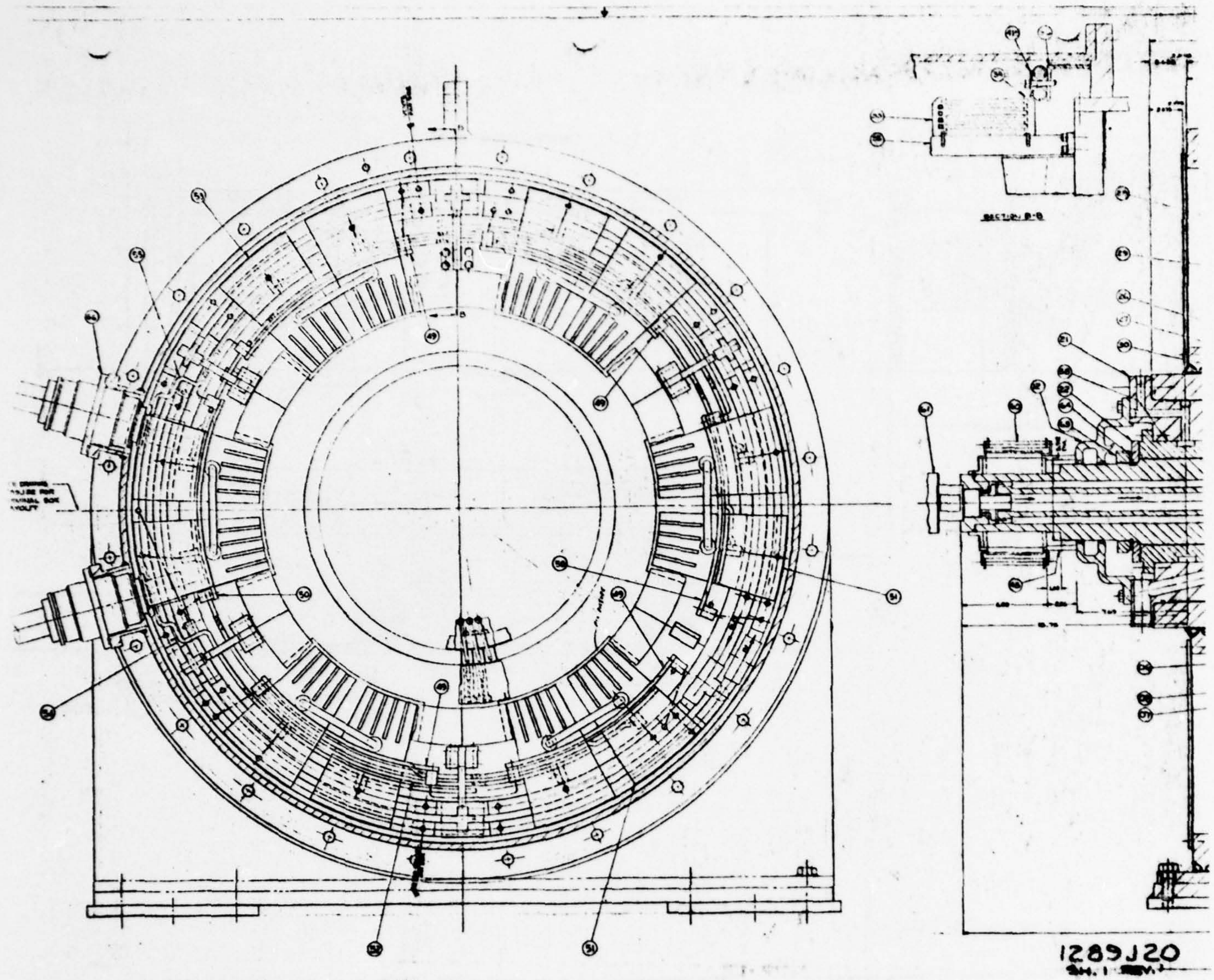

5,000 HP 4 POLE MOTOR
WELDING - ROTOR FORGING
01 ROTOR SEGMENT
02 ROTOR SEGMENT
03 COOLANT GUIDE
04 END CAP
05 A EYE BOLT
06 B WELD INSERT
A - REID TOOL SUPPLY CO. 2233 TEMPLE ST. MUSKEGON HEIGHTS, MICHIGAN
B - ARCO CORP., 1500 SO. 50TH ST., PHILADELPHIA, PA. 19143
LOCALLY - WILLIAMS & CO.
NOTES:
1- CLEAN GROUP-1 THIS DRAWING (EXCEPT ITEM-05) PER DRAWING
2- HEAT ROTOR SEGMENT (ITEM-01) TO 375° F & INSTALL COOLANT GUIDE AS SHOWN. MAINTAIN AXIAL PRESSURE ON ITEM-03 UNTIL
3- WELD PER PS. 82127 NL & PT EACH LAYER.
4- WELD PER PS. 82127 NA & PT FINAL LAYER.
5- STRESS RELIEVE AS FOLLOWS AFTER WELDING & BEFORE MACHINING. ANNEAL SHAFT IN A CONTROLLED ATMOSPHERE FURNACE TO MINIMIZE OXIDATION, SUSPEND SHAFT VERTICALLY & HEAT TO 1150° ± 50° F & HOLD FOR 60 MINUTES, FURNACE COOL TO 600° F AT A TEMPERATURE DECAY RATE NOT EXCEEDING 200° F/HR.
6- INDICATE ALONG THIS SURFACE FROM THIS SIDE FOR A LENGTH OF 52.00 INCHES APPROX. TO ESTABLISH BEST CENTERING POSITION & MACHINE SURFACE AS NOTED.
7- COVER ALL OPENINGS DURING ALL PHASES OF MANUFACTURING TO MAINTAIN INTERNAL CLEANLINESS.
VIEW C-C
SECTION D-D
TYP 4 PLACES AS SHOWN
94.25 APPROX.
ORIENTATION KEY (BEFORE WELDING & MACHINING)
1000-8 THD. x 3.00 DP
Westinghouse Electric Corporation
5000 HP 6 POLE MOTOR
WELDING ROTOR FORGINGS
1435E21

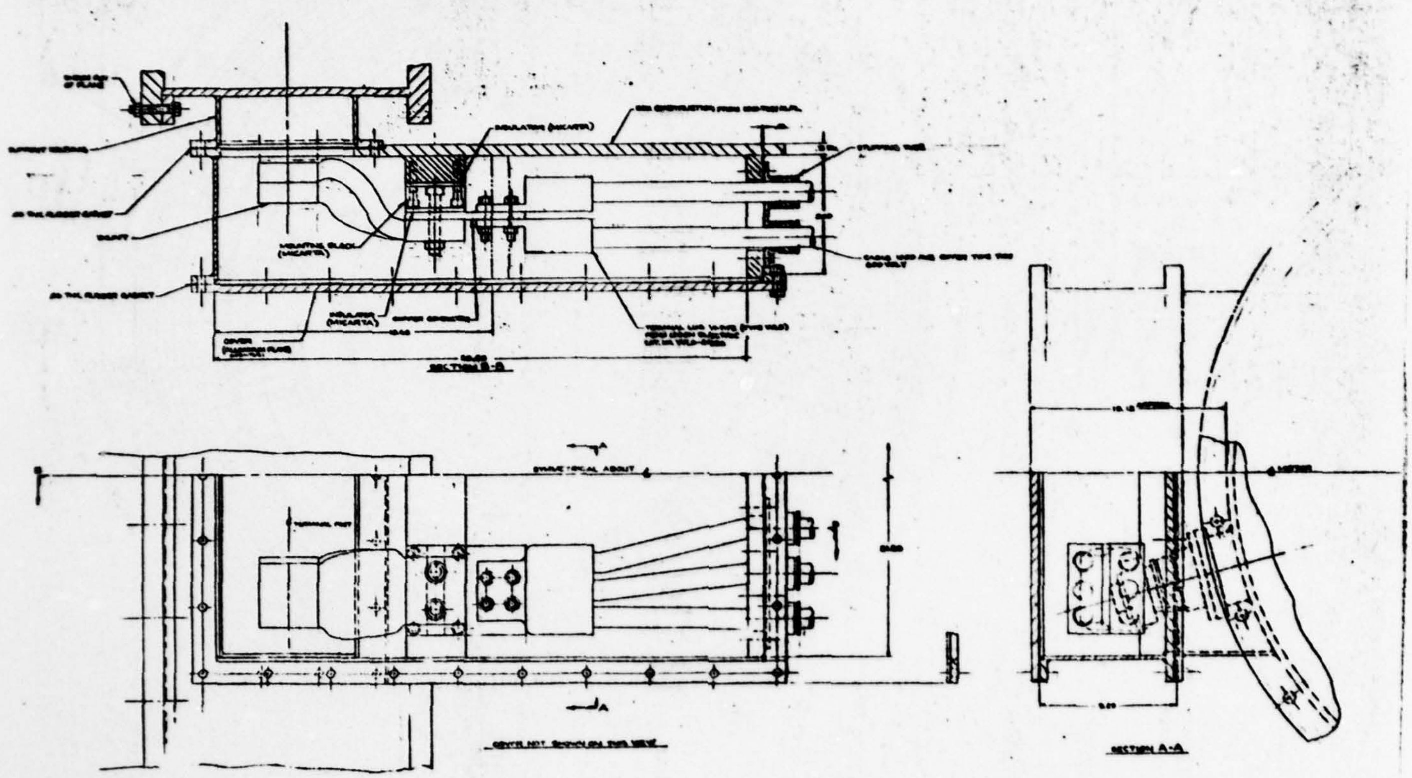

1435E22


SECTION A-A

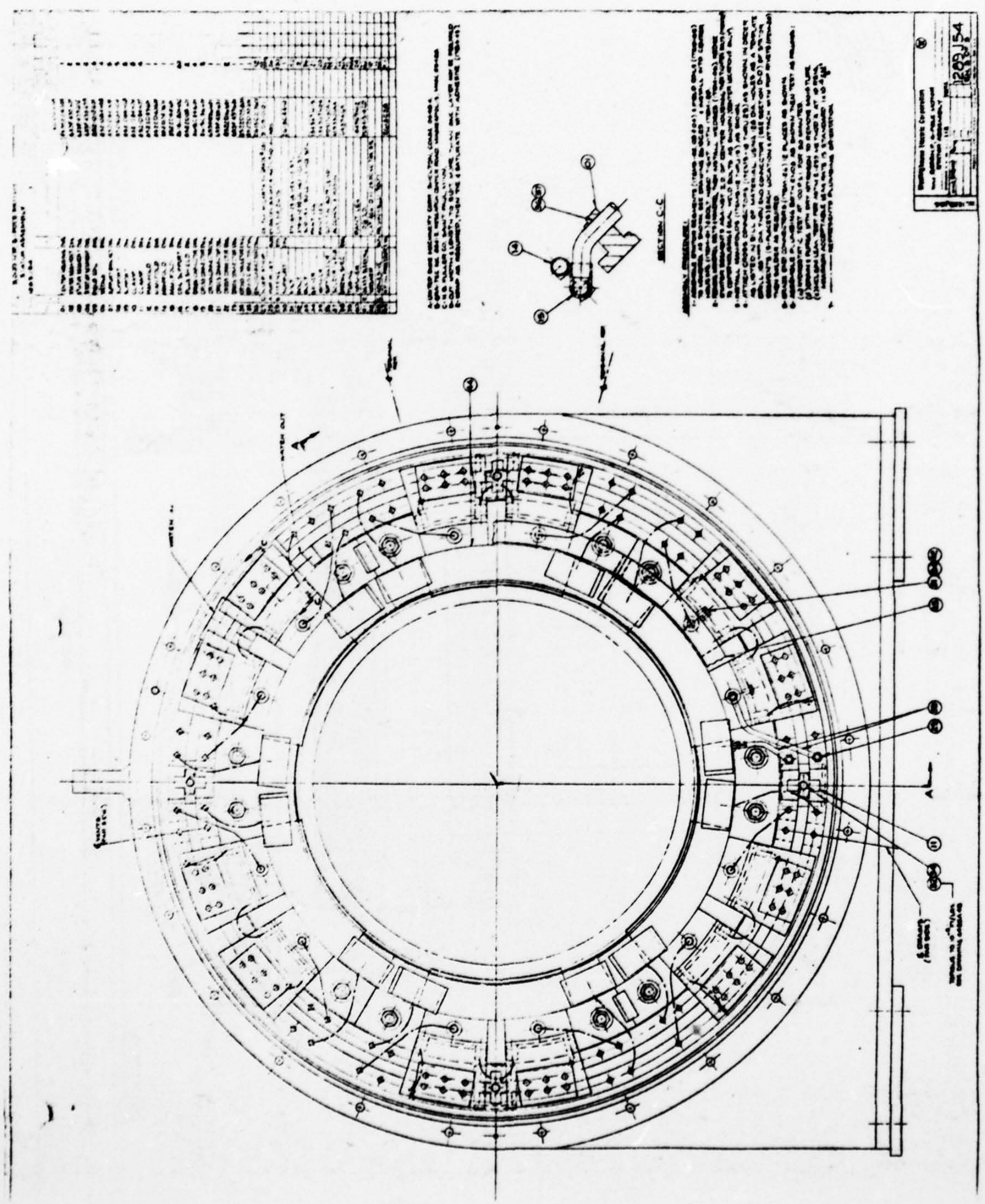

Electric Corporation
4000 H.P., 6 POLE MOTOR
LAYOUT (CONCEPTUAL)
1289J20

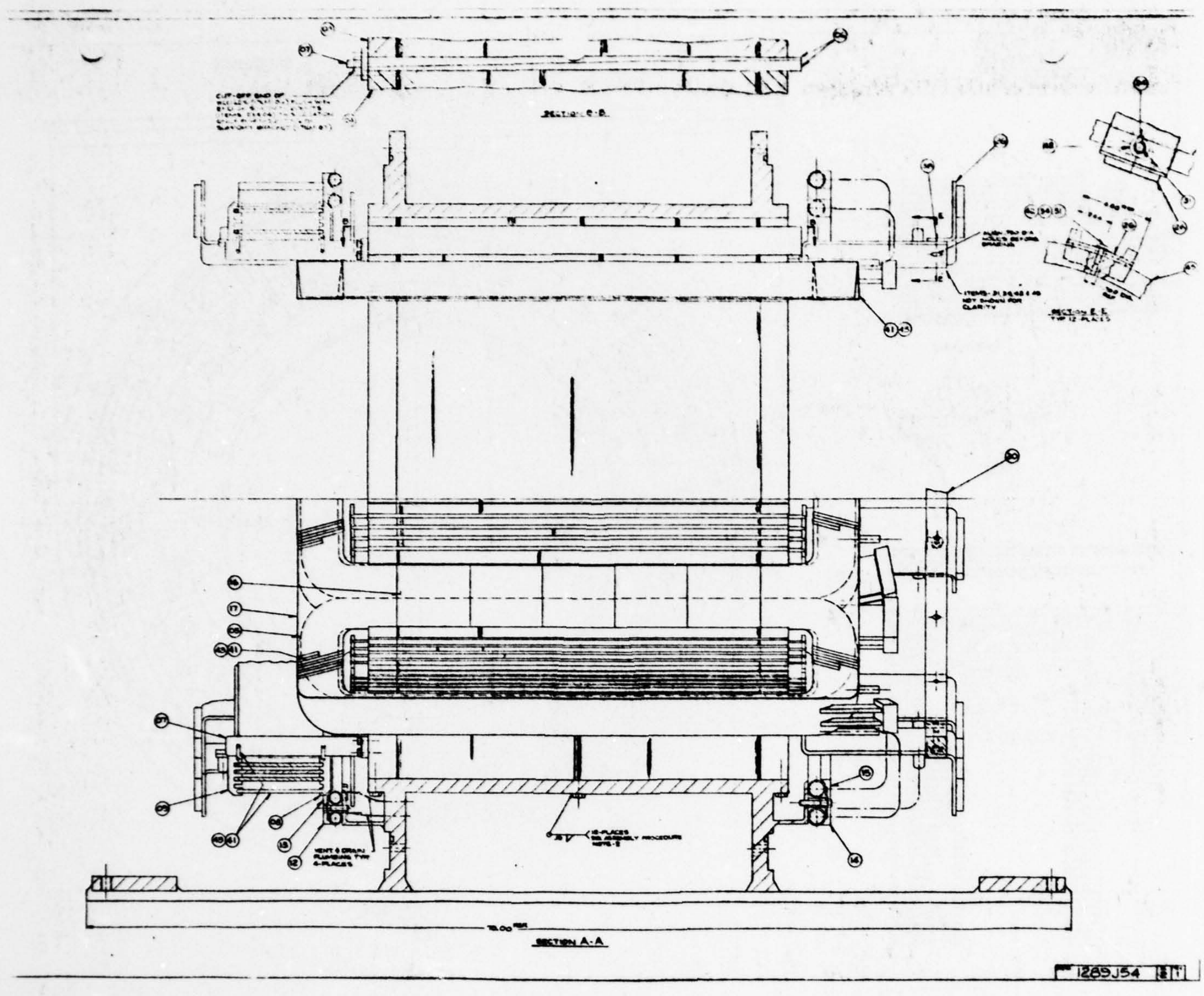



SECTION B-B
1289J20
SH. 1 REV.

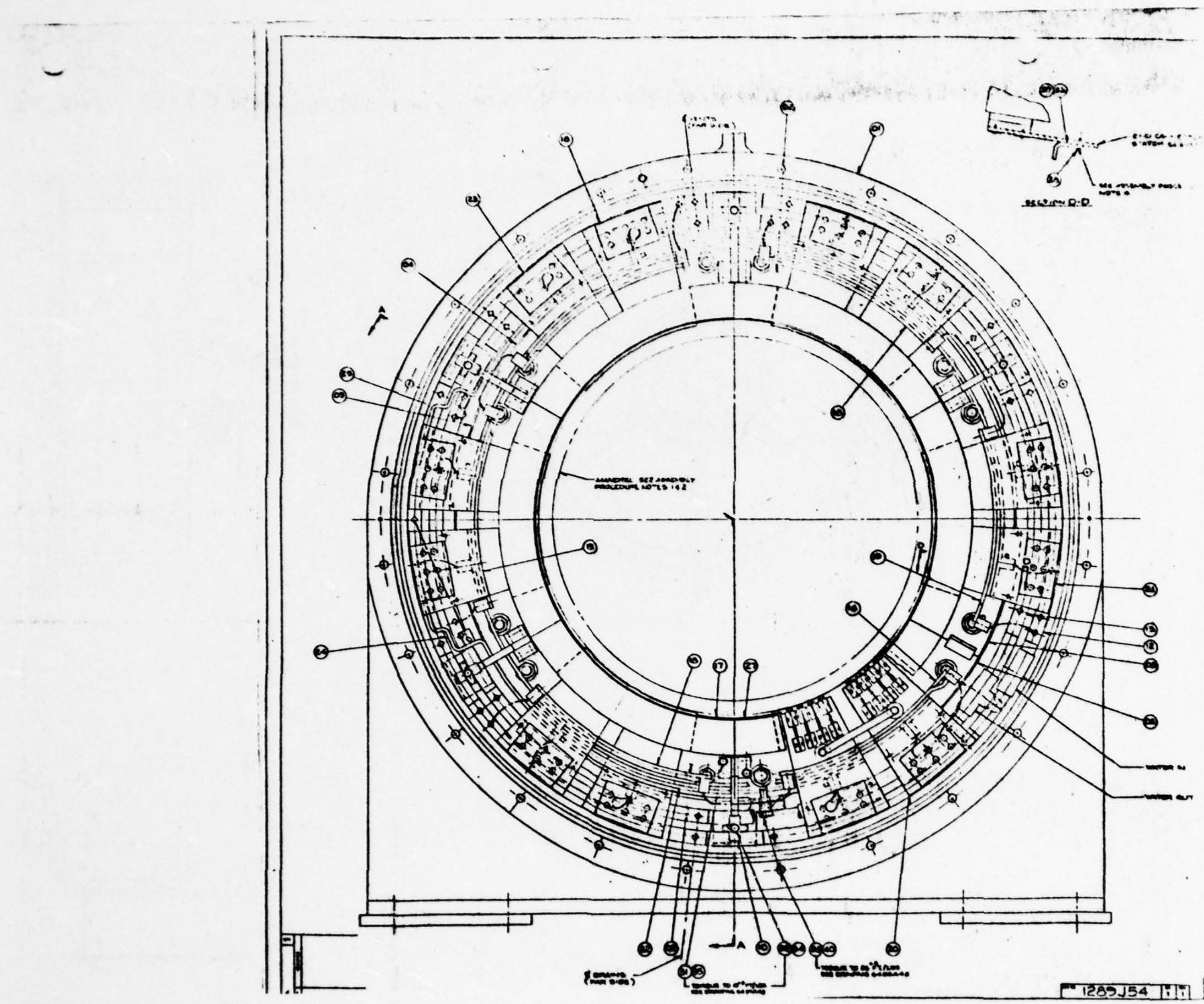


1289J32

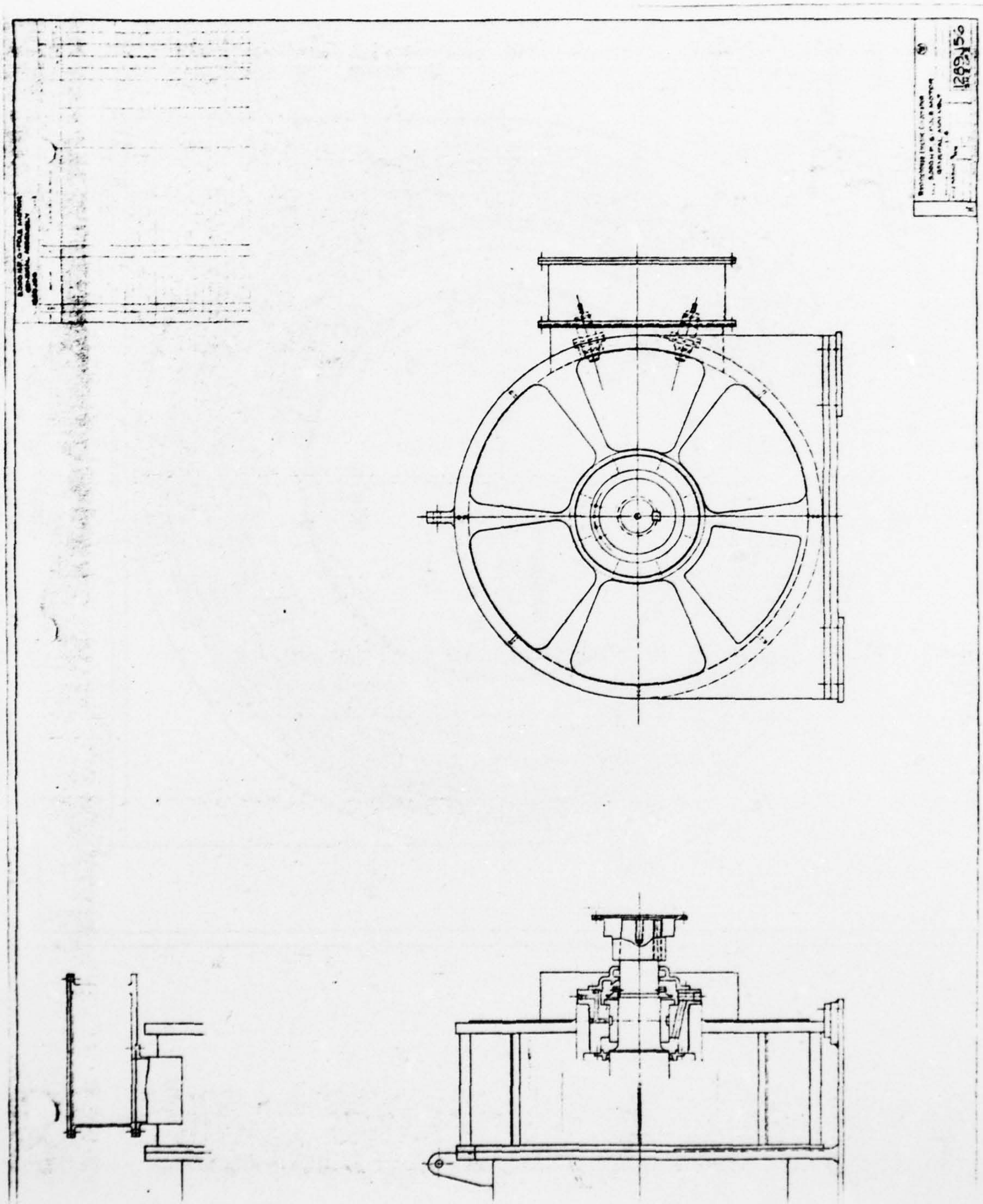


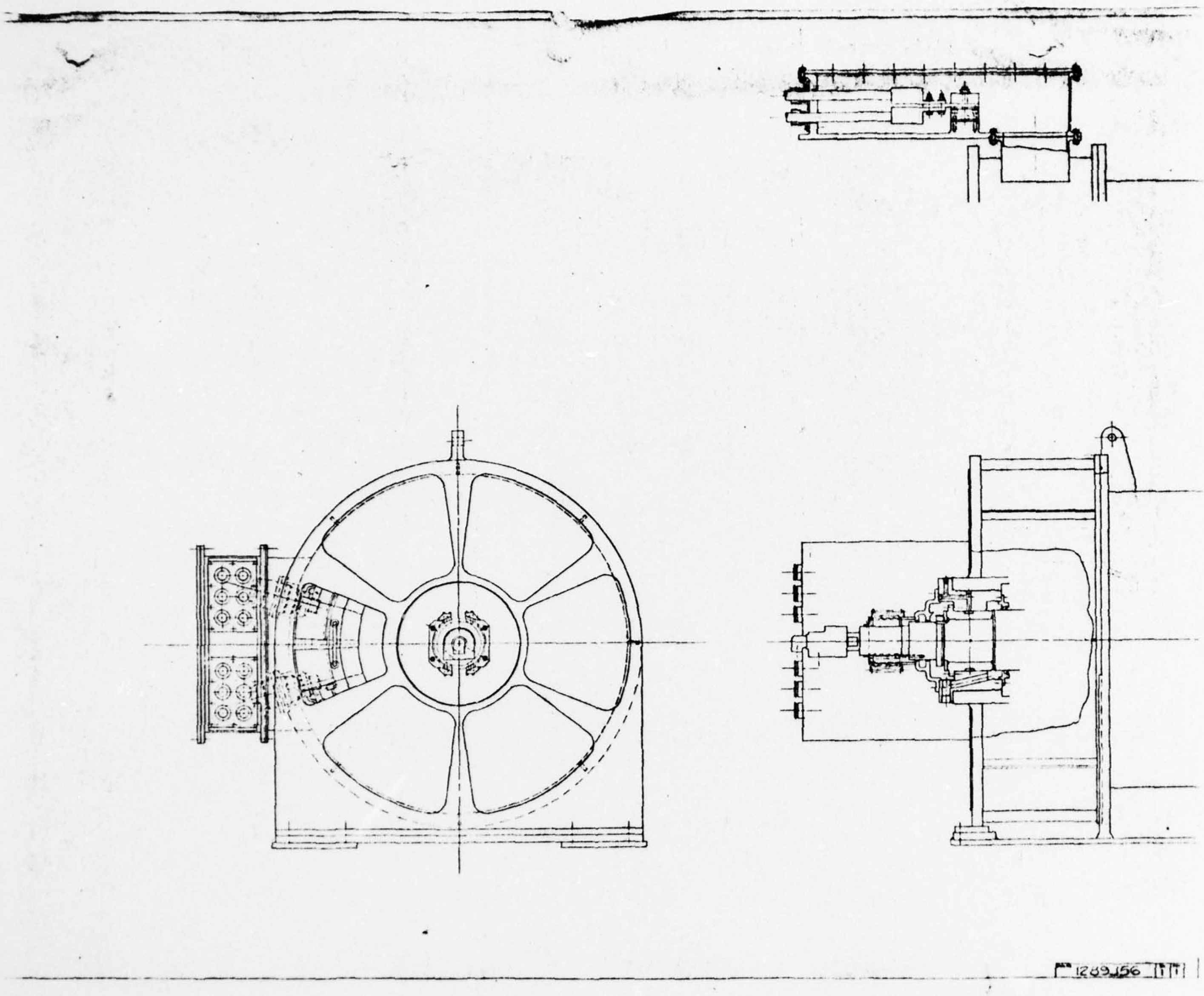


SECTION C-C
SECTION E-E
SECTION A-A
1269J54



SECTION D-D
WATER IN
WATER OUT
1289J54


GENERAL ASSEMBLY
1289J50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